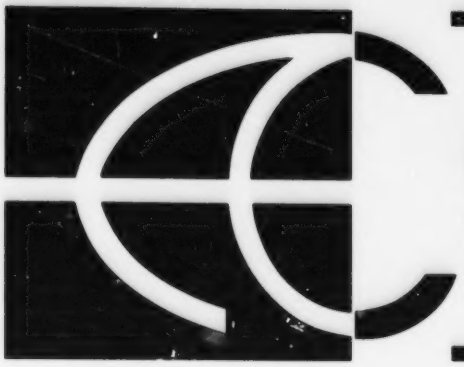

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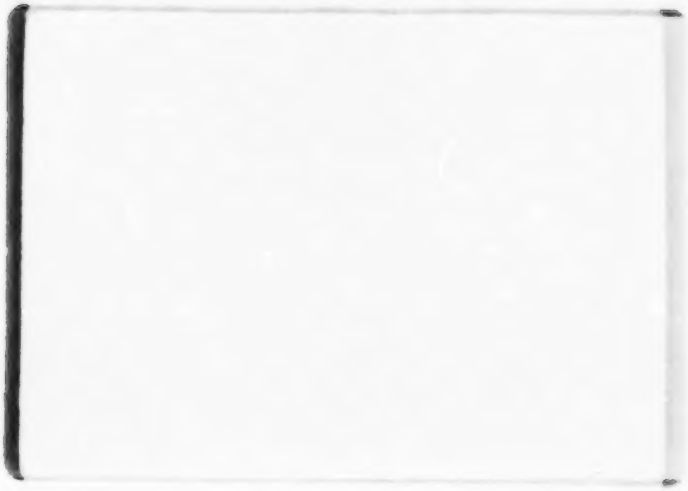

DEVELOPMENT OF TECHNOLOGY TO UTILIZE

EXISTING TOBACCO KILNS

AND/OR

TOBACCO STORAGE BARNS FOR CURING (DRYING)

AND/OR

STORAGE OF OTHER CROPS

Report No. 88-5103 March, 1988

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DEVELOPMENT OF TECHNOLOGY TO UTILIZE EXISTING TOBACCO KILNS AND/OR TOBACCO STORAGE BARNS FOR CURING (DRYING) AND/OR STORAGE OF OTHER CROPS

Report No. 88-5103 March, 1988

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ABSTRACT

Methods to utilize existing bulk tobacco kilns for curing (drying) of shelled corn, peanuts, and baled hay were investigated.

Results from the projects indicate: shelled corn can be dried from about 26% moisture content (w.b.) or less; baled hay can be dried from about 27% moisture content (w.b.) or less; and peanuts cured at airflow rates ranging from 169 to 645 litres per second per cubic metre of peanuts exhibited no significant differences when evaluated for appearance and flavour.

INTRODUCTION

In recent years Ontario tobacco producers have had to reduce production levels due to a declining demand for flue-cured tobacco. Many tobacco producers are presently diversifying into other crops. Some of these crops require curing and/or storage. Because of high capital costs to purchase conventional curing and/or storage facilities, tobacco producers wish to reduce their initial diversification costs by modifying their existing tobacco kilns (tobacco drying structures) and/or tobacco storage barns for this purpose.

Every flue-curing tobacco farm in the province is equipped with either stick or bulk kilns. The number of kilns on each farm varies, however, there are usually at least 8 kilns per farm. In addition, each farm has one or more tobacco storage barns (commonly referred to as pack barns).

Two distinct styles of downdraft stick kilns exist: high profile and low profile (see figures 1 and 2). High profile downdraft kilns have exterior dimensions of about 7300mm (l) x 6800 mm (w) x 4500 mm (h) whereas low profile downdraft kilns have exterior dimensions of about 10000 mm (l) x 6100 mm(w) x 3500 mm (h). The height measurement of both kiln styles is from grade to the eave.

Downdraft stick kilns are fan-forced, tobacco curing systems. Air is forced through the tobacco by an axial flow fan contained in an external, wall mounted, metal clad duct (commonly referred to as the blower/burner duct). The fan operates at approximately 430 rpm and delivers 3700 to 4700 L/s of air. The fan is belt driven by a 0.7 kW electric motor.

Air within a downdraft kiln passes up through the blower/burner duct into the upper plenum of the kiln, downward

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The mention of manufacturer's trade names is for the purpose of specific product description and does not indicate endorsement or criticism of that product or products not mentioned by the authors or the Ontario Ministry of Agriculture and Food.

through the hanging tobacco and returns either to the air intake of the blower/burner duct or is expelled out exhaust louvres.

Air exchange is controlled by adjustment of the fresh air intake vent(s) located on the blower/burner duct. Opening the air intake vent(s) allows cooler, drier air to be drawn into the kiln. This pressurizes the kiln. Two pressure sensitive exhaust louvres located at the lower corners of the kiln wall relieve the internal pressure by allowing moisture-laden air to escape to the atmosphere.

Downdraft kilns are direct-fired with natural gas, propane or no. 2 oil. The fuel energy input of the burners will vary with many being in the range of 740 to 790 MJ/h.

The majority of downdraft kilns were constructed without insulation thirty to forty years ago. Due to increasing energy costs many downdraft kilns have since been partially or completely sealed with polyurethane foam.

The construction of bulk kilns differs appreciably from downdraft kilns (see figure 3). Typical exterior dimensions of a bulk kiln are about 12500 mm (l) x 3050 mm (w) x 3330 mm (h). Depending upon the manufacturer, many kilns are insulated with fiberglass batts in the walls and expanded polystyrene on the under-side of the roof.

The direction of air circulation in bulk kilns is the reverse of that in downdraft kilns. Air is forced into the lower plenum of the kiln and up through a perforated metal floor. The air then passes through the tobacco and either recirculates to the blower/burner unit or is expelled out exhaust louvres located above the loading doors of the kiln. Similar to the method of air exchange in downdraft kilns, opening the fresh air intake vent(s) on the blower/burner unit increases the air pressure within the kiln and forces moisture-laden air out through the exhaust louvres.

Air within a bulk kiln is circulated by a centrifugal blower powered by either a 3.7 kW or 5.6 kW electric motor. Airflow rates will vary depending upon the kiln manufacturer, however, most are in the range of 5600 to 7000 L/s.

The majority of bulk kilns are equipped with direct-fired burners fuelled by either natural gas or propane. A small percentage of bulk kilns are equipped with indirect fired burners fuelled by no. 2 oil. Combustion efficiency of the burners range from 59% with no. 2 oil to 85% for propane or natural gas. The majority of bulk kiln burners operate in the range of 295 to 410 MJ/h input.

Tobacco pack barns are used for grading and storage of tobacco as well as for equipment storage (see figure 4). Barn dimensions and styles vary among farms. Most barns are equipped with a heater/humidifier unit used for conditioning tobacco during grading.

During 1982 and 1983, the Agricultural Energy Centre of the Ontario Ministry of Agriculture and Food, investigated the merits of utilizing tobacco kilns to cure peanuts. On-farm demonstrations indicated that bulk kilns can be successfully used for this purpose. However, peanut growers and processors have indicated that more research is required to "fine-tune" the curing process so that optimum cured quality can be attained.

In addition, other tobacco growers making the transition to other crops, are inquiring about the possibilities of utilizing tobacco kilns and/or tobacco barns for curing and/or storage of crops such as hay, corn, sweet potatoes, garlic, ginseng, flowers, onions, lumber, etc.

In 1987, with the financial assistance from the Alternate Enterprise Initiative Program, three projects were undertaken which investigated some of these requests: i) drying and storing shelled corn in bulk tobacco kilns; ii) effects of airflow rates in relation to the curing and quality of peanuts; and iii) curing hay in bulk tobacco kilns. The findings of each project follow in sections i, ii and iii of this report.

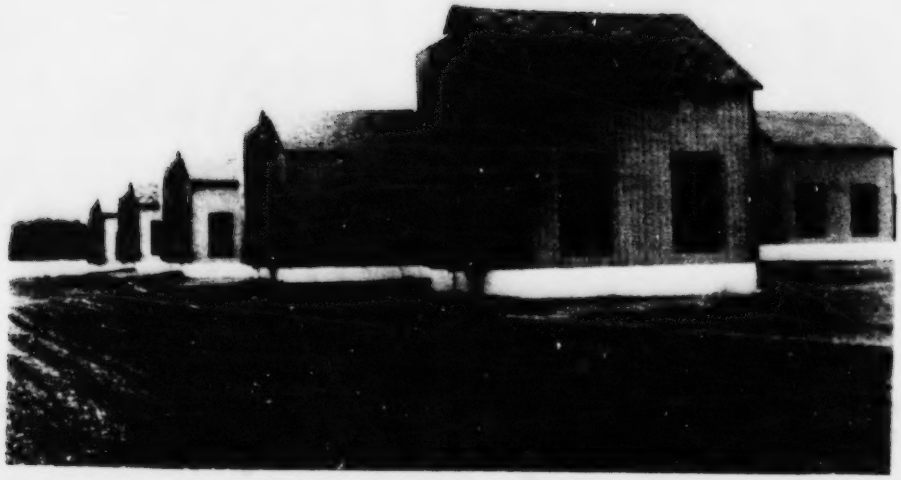

Figure 1: High profile downdraft stick kilns

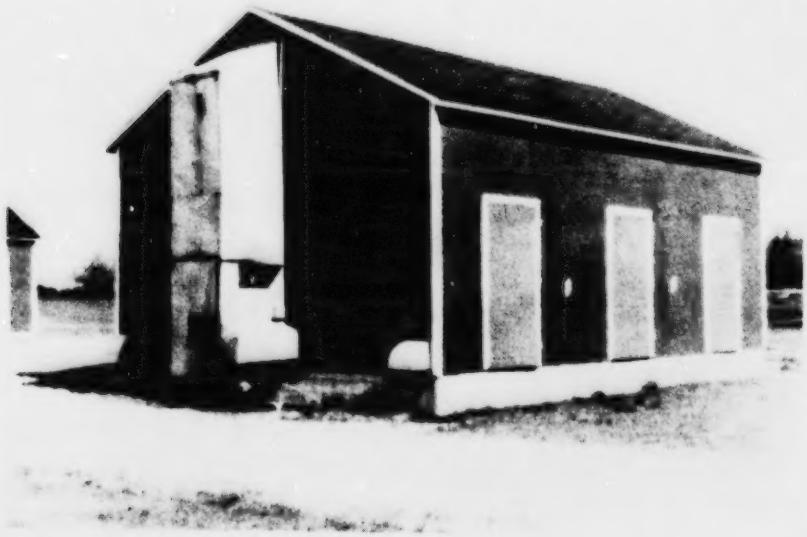

Figure 2: Low profile downdraft stick kiln

Figure 3: Bulk kilns

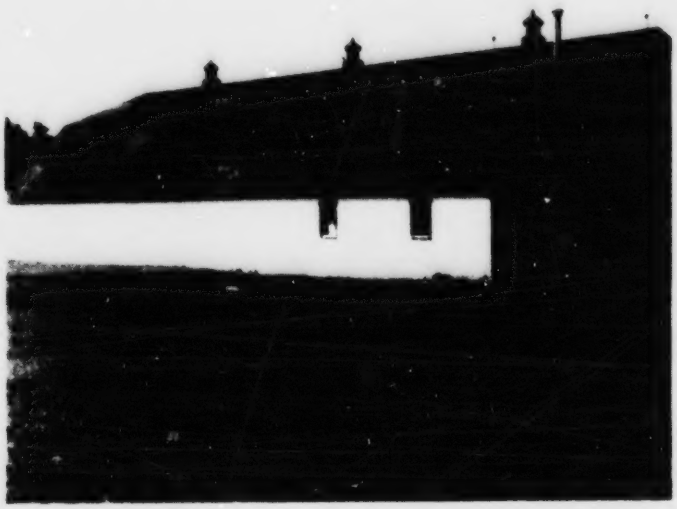

Figure 4: A typical tobacco pack barn

i) DRYING AND STORAGE OF SHELLED CORN IN BULK KILNS

BACKGROUND

Some tobacco growers are utilizing their bulk kilns to dry and store shelled corn. However, there are no corn drying and storage guidelines available which are specific to bulk tobacco kilns. Most growers are drying and storing corn on a trial and error basis, some are successful while others are not.

In cooperation with Albert, Gilbert and Marcel Vankerrebroeck of Norwich, a project was initiated at their farms to record their method of drying and storing shelled corn in bulk tobacco kilns. The Vankerrebroecks were choosen because of their success during ten years of drying and storing approximately 650 tonnes of shelled corn annually in 21 bulk kilns.

OBJECTIVE

The objective of the project was to monitor a farm operation that successfully dries and stores shelled corn in bulk kilns. The following were investigated:

a) bulk kiln modifications;
b) corn handling methods;
c) drying and storage methods;
d) and energy requirements.

METHOD

Kiln Specifications

The bulk kilns on the Vankerrebroeck farms are "Powell" units. Each kiln has the capacity of 150 racks. Inside dimensions of the curing compartment are about 10000 mm (l) x 3040 mm (w) x 2440 (h) (height measurement from perforated floor to eave).

Each kiln is equipped with a "Powell model no. 511" blower/burner unit. The centrifugal blower of the blower/burner unit is powered by a 3.7 kW motor. The airflow capacity of the blower is rated at 4700 L/s (kiln manufacturer's rating). The burner of the blower/burner unit is direct-fired with natural gas. The fuel energy input of the burner is rated at 295 MJ/h. A 25 mm thickness of polyurethane foam lines the complete interior of each kiln's roof. The walls of the kilns are not insulated.

Kiln Modifications

The Vankerrebroecks have found that to utilize their bulk kilns for drying and storing of shelled corn kiln modifications were required.

The most extensive modification to each kiln was the installation of chains to reinforce the sidewalls of the kiln. A total of eight chains (6 mm diameter), spaced every 1200 mm from the blower/burner wall, run laterally connecting the sidewalls 550 mm above the perforated floor. The chains prevent the lateral pressure exerted by the corn from pushing out the sidewalls.

Another modification involved blocking the return air inlet of the blower/burner unit of each kiln. Heavy plastic was stapled in front of the return air inlet of the blower/burner unit to prevent drying air (moisture-laden) that has passed through the corn from being recycled. Thus, since the drying air is not recirculated, it's expelled through the exhaust louvres located above the loading doors.

It should be noted that blocking the recirculation air inlet of the blower/burner unit without opening the fresh air intake vent(s) on the blower/burner unit will starve the blower for air. The fresh air intake vent(s) must be fully open to prevent air starvation.

A minor modification is the use of boards which are fitted across the loading end of the kiln. This retains the corn in the bulk kiln and prevents corn from exiting the kiln when the loading doors are opened.

Handling Methods

Corn is transported from the field to the kiln yard using grain wagons. A pneumatic conveyor powered by the pto of a 75 kW tractor is used to convey the corn into and out of the kilns. During filling the suction end of the pneumatic conveyor is placed on a tarp below the gate opening of the grain wagon. Corn discharging from the wagon enters the suction end of the pneumatic conveyor. The discharge end of the pneumatic conveyor is located in the kiln on a trolley located on the top rack support rails. The corn is discharged directly onto the perforated floor starting at the blower/burner end. The trolley is slowly pulled back towards the loading end of the kiln when the desired corn depth has been reached. After filling is completed, the corn is levelled using a rake and shovel.

Unloading the bulk kilns requires the suction end of the pneumatic conveyor to be held to "vaccum" up the corn while the discharge end of the pneumatic conveyor is located over the receiving truck.

The amount of labour and time required to load a bulk kiln is dependant upon the harvesting rate. Unloading a bulk kiln requires 3 men for a one hour period.

Loading Depth

The Vankerrebroecks normally dry corn in layers in their bulk kilns. The depth of the first layer is usually between 650 mm and 850 mm. After the first layer is dried down to an average of 15 to 18% moisture content (w.b.) a second layer is loaded on top of it. The depth of the second layer is usually between 500 and 850 mm. Drying is complete when the average moisture content of the two layers reaches 15 to 16% m.c. (w.b.).

However, in 1987, in the eight bulk kilns that were monitored, the Vankerrebroecks dried their corn differently. All eight bulk kilns were filled with corn to a depth of 650 to 850 mm. After drying, three of the eight bulk kilns were unloaded and refilled. Wet corn was loaded to a depth of 1400 to 1500 mm in two of the bulk kilns and dried, while the third bulk kiln was loaded and dried in two consecutive layers.

MONITORING

Eight bulk tobacco kilns were selected for monitoring. The manifold pressure of each kiln burner was set at a pressure of 870 Pa. Time clocks were used to determine the fuel consumption of each kiln. Each bulk kiln was equipped with a time clock installed in the electrical line between the thermostat and the gas valve of the burner. Each time clock recorded the number of continuous hours of operation of the burner. Natural gas meters were also installed on two of the eight bulk kilns to determine the fuel energy input (megajoules per hour) of the burners. Fuel consumption of each kiln was determined by multiplying the total hours accumulated on the time clock by the megajoules per hour (MJ/h) input of the burner derived from the gas meters.

Electrical consumption of the motors operating the blowers of the bulk kilns was determined from the kWh meter servicing the kiln yard.

As the bulk kilns were filled samples were taken to determine moisture content. Moisture contents were determined with a "Dickey John Grain Computer" and "Stienlite Model D" moisture meters.

After drying was completed, moisture samples were taken from various depths of the corn layer. When a layer of corn 650 to 850 mm deep was dried samples were taken from the bottom 100 mm of the layer, middle portion of the layer and the top 100 mm of the layer. When a layer of corn 1400 to 1500 mm deep was dried moisture samples were taken from the bottom 300 mm of layer, middle of the layer and top 100 mm of the layer. This procedure was repeated when two consecutive layers of corn were dried. In addition, a mixed sample of corn from each kiln was taken to determine an average moisture content of the layer(s).

Ambient and drying air temperatures were recorded periodically in all kilns using a remote digital temperature

indicator and type K thermocouples. The drying air temperature was measured in the heated plenum of each kiln to determine the temperature rise of the drying air as compared to the ambient air temperature. In addition, a "Kaye-Digi III" datalogger and type K thermocouples were used to record the hourly average temperatures of the drying air and ambient air during drying in one of the eight bulk kilns.

RESULTS AND EVALUATION

Single Layer Drying (initial corn depth 650 to 850 mm)

Table 1C shows the data collected when a layer of corn was dried in each of the eight bulk kilns. The average loading depth per kiln was 742 mm. An average of 16.926 tonnes of corn at 24.26% moisture content (w.b.) was in each kiln. Drying was completed after an average of 50.4 h of continuous blower operation during which the burner operated continuously for an average of 38.8 h during the initial period of drying. After drying and cooling, approximately 15.312 tonnes of corn at 16.28% moisture content (w.b.) was contained in each kiln. On average, 8 points of moisture were removed from the corn.

During drying the burner thermostats in all eight bulk kilns were set at 38°C, however, the drying air temperature never reached 38°C. The burner of each kiln operated continuously during drying. The heat output of the burner was not large enough to raise the temperature of the large volume of cold ambient air to 38°C. Random checks of the drying air temperature of each kiln indicated that the average temperature rise of the ambient air was about 11 C°.

Table 2C indicates the amount of energy required to remove the 8 points of moisture from the corn. For every kilogram of water removed from the corn an average of 6.72 megajoules (MJ) of natural gas and 0.26 MJ of electricity were consumed. Overall, an average of 6.98 MJ was consumed per kilogram of water removed.

It should be noted that each bulk kiln consumed an average of 282 m^3 or 10630 MJ of natural gas during 38.8 h of continuous burner operation. Thus, the average energy input of the eight bulk kiln burners was approximately 274 MJ/h which is approximately 7% less than the manufacturer's burner specification of 295 MJ/h.

Table 3C shows the costs of drying the single layer of corn in each of the bulk kilns. Natural gas and hydro costs for the eight bulk kilns totalled $406.62 and $45.95, respectively. Based on a dried corn mass of 122.499 tonnes @ 16.28% moisture content (w.b.), the average cost to remove the 8 points of moisture amounted to $3.69 per tonne of dry corn.

The average airflow rate per kiln can be estimated from the following observations and calculations:

air temperature rise = 11C°;

energy input of burner = 274 MJ/h;

energy output of burner (assuming a combustion efficiency of 85%) = 233 MJ/h

Airflow can be calculated mathematically by:

$$V = \frac{Q}{Cp\ Diff\ T} \times \frac{1h}{3600s}$$

where

V = airflow , L/s;

Q = heat output of burner, MJ/h;

Cp = specific heat of air, 1.2 J/L·C°;

DiffT = temperature rise of air, C°;

$$V = \frac{233\ MJ/h}{(1.2\ J/L{\cdot}C°)\ \ (11\ C°)} \times \frac{1\ h}{3600s}$$

V = 4903 L/s

Since each kiln contained an average of 20.09 m^3 of dry corn (from table 1C), the airflow rate was about 244 L/s/m^3 of dry corn.

Single Layer Drying (initial corn depth 1400 to 1500 mm)

Two of the eight bulk kilns were unloaded and refilled with corn to a depth of between 1400 and 1500 mm. As indicated in table 4C an average of 32.151 tonnes of corn at 22.26% moisture content (w.b.) was dried per kiln. Drying and cooling was completed after an average of 141.1 h of continuous blower operation during which the burner operated continuously for an average of 105.0 h during the initial period of drying. After drying, an average of approximately 28.484 tonnes of corn @ 12.25% moisture content (w.b.) was contained in each kiln. On average, 10 points of moisture were removed from the corn in the two bulk kilns.

The temperature setting of the thermostats was again 38°C. Random checks of the plenum air temperature indicated that the temperature rise of the drying air never exceeded 19 C°.

This was verified by temperatures recorded with the datalogger in one of the bulk kilns. Figure 1C illustrates the drying and ambient air temperatures recorded by the datalogger over a 36 h period. The average air temperature rise was 18.9 C°.

It is conceivable that the drying air temperature could reach 38 °C if the ambient temperature is 19°C or warmer, however, since drying takes place during late October and November, the possibility of this occurring is unlikely.

Table 5C indicates the energy consumed to remove the 10 points of moisture from the corn. For every kilogram of water removed from the corn an average of 7.91 MJ of natural gas and 0.32 MJ of electricity were consumed. Overall, an average of 8.23 MJ of energy was consumed per kilogram of water removed.

As compared to the energy requirements to remove water at the 650 to 850 mm depth, drying 1400 to 1500 mm of corn required approximately 13% more energy. However, more replications are required before any conclusions should be made since the corn was overdried to 12.25% moisture content (w.b.).

Table 6C indicates the costs to dry 1400 to 1500 mm of corn. Natural gas and hydro costs for the two bulk kilns totalled

$275.22 and $32.22, respectively. Based on a dried corn mass of 56.968 tonnes @ 12.25% moisture content (w.b.), the average cost to remove the 10 points of moisture amounted to $5.40 per tonne of dry corn.

The average airflow rate can be estimated in the same manner as in the previous section:

$$V = \frac{233\ MJ/h}{(1.2\ J/L \cdot C^\circ)\ (19\ C^\circ)} \times \frac{1\ h}{3600s}$$

$V = 2839\ L/s$

The airflow rate per kiln was about 78 $L/s/m^3$ of dry corn based on a corn volume of 36.26 m^3 per kiln (from table 4C). Thus, increasing the depth of the corn layer (from 650 to 850 mm) to 1400 to 1500 mm resulted in a 42% decrease in airflow and permitted the increase in temperature rise from 11 C° to 19 C°.

Double Layer Drying

Corn from one of the eight bulk kilns was removed and the bulk kiln was reloaded. Corn was filled to a depth of 1018 mm. The initial corn mass was 22.718 tonnes @ 21.00% moisture content (w.b.). The burner operated continuously for 42.1 h while the blower was operated continuously for 51.8 h. The temperature setting of the burner was 38°C, however, the temperature rise of the ambient air did not exceed 15 C°. After completion of drying the moisture content of the corn averaged 15.10% (w.b.).

A second layer of corn was loaded on top of the dried layer. The depth of the second layer was 498 mm. The corn mass of the second layer was 10.374 tonnes @ 22.50%. The blower was operated for 96.3 h during which the burner operated for the intial 47.7 h of drying. The temperature rise of the ambient air did not exceed 19 C°. After completion of drying the corn mass totalled 29.682 tonnes @ 12.45% moisture content (w.b.).

Natural gas and hydro consumption amounted to 654 m^3 and 335 kWh, respectively. For every kilogram of water removed about 7.23 MJ of natural gas and 0.35 MJ of hydro were required.

Total energy consumption was 7.58 MJ per kilogram of water removed. The cost to remove the 9 points of moisture amounted to $4.54 per tonne of dry corn.

DISCUSSION

Figures 2C and 3C illustrate the variation in moisture content resulting from drying deep layers of corn using heated air. Drying a single layer of corn with an initial depth of 650 to 850 mm resulted in various moisture contents throughout the layer: 12 to 13% m.c. (w.b.) within 100 mm of the drying floor; 14 to 19% m.c. (w.b.) in the middle of the layer; and 16 to 22% m.c. (w.b.) in the top 100 mm of the layer. Drying a single layer of corn with an initial depth of 1400 to 1500 mm resulted in 11% m.c. (w.b.) corn within 300 mm of the drying floor and 14 to 15% m.c. (w.b.) corn at the top of the layer. Similar results were observed with drying two consecutive layers.

The variation in moisture content throughout the total corn depth make it extremely difficult to determine when the average moisture content of the layer(s) is 15.5% (w.b.). Tables 1C and 4C indicated that after drying was completed the average moisture content of the corn layer was usually over or under 15.5% m.c. (w.b.). Overdrying increases energy consumption and decreases the potential marketable weight, whereas underdrying increases the potential for spoilage during storage.

Because of the large air capacity of the blowers in bulk kilns, future consideration should be given to natural air drying. This would reduce overdrying, increase drying time and probably reduce drying costs. Another aspect that could be tested would include partial recirculation of heated drying air to reduce overdrying of the lower portion of the corn layer.

The management practices of storing corn in bulk kilns has not been addressed because monitoring is still ongoing.

CONCLUSIONS

1) Drying corn in bulk kilns requires modifications: reinforcement of the kiln sidewalls to prevent structural damage; controlling the return air inlet of the blower to prevent moisture-laden air from recirculating through the corn; full opening of the fresh air intake vents on the blower/burner unit to prevent the blower from starving for air; and boards fitted across the loading end of the kiln to retain the corn in the kiln.
2) Corn at about 26% moisture content (w.b.) or less can be dried in bulk kilns.
3) The temperature of the drying air will depend upon airflow, burner size and ambient temperature.
4) Airflow will depend upon the depth of corn being dried.
5) Removing 8 to 10 points of moisture from corn dried in bulk kilns requires 6.72 to 7.91 MJ of natural gas and 0.26 to 0.32 MJ of electricity per kilogram of water removed.
6) Based on 1987 energy prices, removing 8 to 10 points of moisture from corn dried in bulk kilns costs $3.69 to $5.40 per tonne of dry corn. The higher cost resulted from overdrying the corn to 12.25% moisture content (w.b.).
7) Drying corn in a layer or two consecutive layers in bulk kilns results in variable dried moisture contents.

RECOMMENDATIONS

Monitoring at the Vankerrebroeck farms should be continued in 1988. Natural air drying and partial recirculation of drying air should be included in the project.

TABLE 1C: Data collected from drying a single layer of corn 650 to 850 mm deep

Kiln #	DEPTH initial (mm)	DEPTH final (mm)	VOLUME initial (m^3)	VOLUME final (m^3)	ESTIMATED CORN MASS* @ MOISTURE CONTENT (w.b.) initial (kg @ %)	ESTIMATED CORN MASS* @ MOISTURE CONTENT (w.b.) final (kg @ %)	BURNER Operation (h)	BLOWER Operation (h)
1	686	617	20.85	18.76	16380 @ 24.38	14470 @ 14.40	40.9	72.5
2	673	589	20.46	17.91	16010 @ 23.36	14410 @ 14.85	40.9	56.8
3	749	665	22.77	20.22	15576 @ 24.39	14241 @ 17.30	36.5	43.5
4	762	671	23.16	20.40	17561 @ 22.59	16398 @ 17.10	36.5	43.5
5	765	699	23.26	21.25	17931 @ 23.08	16390 @ 15.85	36.4	43.5
6	767	693	23.32	21.07	17449 @ 25.64	15680 @ 17.25	36.1	43.5
7	714	617	21.71	18.76	15934 @ 24.79	14233 @ 15.80	36.3	43.5
8	823	734	25.02	22.31	18565 @ 25.80	16677 @ 17.40	46.6	56.5
Ave Per Kiln	742	661	22.57	20.09	16926 @ 24.26**	15312 @ 16.28**	38.8	50.4

*Corn mass was estimated from random samples weighed after completion of drying.

**Weighted average

TABLE 2C: Energy required to dry a single layer of corn 650 to 850 mm deep

Kiln #	H_2O Removed (kg)	Natural Gas Consumed (m^3)	Hydro Consumed (kWh)	Fuel Energy* per H_2O Removed (MJ/kg)	Electrical Energy* per H_2O Removed (MJ/kg)	Total Energy per H_2O Removed (MJ/kg)
1	1910	298	164	5.88	0.31	6.19
2	1600	298	128	7.02	0.29	7.31
3	1335	266	98	7.51	0.26	7.77
4	1163	266	98	8.62	0.30	8.92
5	1541	265	98	6.48	0.23	6.71
6	1769	263	98	5.60	0.20	5.80
7	1701	264	98	5.85	0.21	6.06
8	1888	339	128	6.77	0.24	7.01
AVE	1613	282	114	6.72	0.26	6.98

*Energy values used - 37.7 MJ/m^3 of natural gas and 3.6 MJ/kWh of electricity

TABLE 3C: Energy costs to dry a single layer of corn 650 to 850 mm deep

Kiln #	Natural Gas @ $0.18/m³ ($)	Hydro @ $0.0505/kWh ($)	Total Cost ($)	Dried Corn Mass @ Moisture Content (w.b.) (kg @ %)	Cost per Corn Mass ($/tonne)
1	53.64	8.28	61.92	14470 @ 14.40	4.28
2	53.64	6.46	60.10	14410 @ 14.85	4.17
3	47.88	4.95	52.83	14241 @ 17.30	3.71
4	47.88	4.95	52.83	16398 @ 17.10	3.22
5	47.70	4.95	52.65	16390 @ 15.85	3.21
6	47.34	4.95	52.29	15680 @ 17.25	3.33
7	47.52	4.95	52.47	14233 @ 15.80	3.69
8	61.02	6.46	67.48	16677 @ 17.40	4.05
TOTAL	406.62	45.95	452.57	122499 @ 16.28*	
AVE					$3.69/tonne @ 16.28% m.c.

*weighted average

TABLE 4C: Data collected from drying a single layer of corn 1400 to 1500 mm deep

Kiln #	DEPTH initial (mm)	DEPTH final (mm)	VOLUME initial (m^3)	VOLUME final (m^3)	ESTIMATED CORN MASS* @ MOISTURE CONTENT (w.b.) initial (kg @ %)	ESTIMATED CORN MASS* @ MOISTURE CONTENT (w.b.) final (kg @ %)	BURNER Operation (h)	BLOWER Operation (h)
2	1486	1196	45.17	36.36	32320 @ 23.30	28363 @ 12.60	105.2	141.1
3	1410	1189	42.86	36.15	31981 @ 21.20	28605 @ 11.90	104.8	141.1
AVE	1448	1193	44.02	36.26	32151 @ 22.26**	28484 @ 12.25**	105.0	141.1

*Corn mass was estimated from random samples weighed after completion of drying

**Weighted average of moisture contents

TABLE 5C: Energy required to dry a single layer of corn 1400 to 1500 mm deep

Kiln #	H_2O Removed (kg)	Natural Gas Consumed (m^3)	Hydro Consumed (kWh)	Fuel Energy* per H_2O Removed (MJ/kg)	Electrical Energy* per H_2O Removed (MJ/kg)	Total Energy per H_2O Removed (MJ/kg)
2	3957	766	319	7.30	0.29	7.59
3	3376	763	319	8.52	0.34	8.86
AVE	3667	765	319	7.91	0.32	8.23

*Energy values used - 37.7 MJ/m^3 of natural gas and 3.6 MJ/kWh of electricity

TABLE 6C: Energy costs to dry a single layer of corn 1400 to 1500 mm deep

Kiln #	Natural Gas @ \$0.18/m^3 (\$)	Hydro @ \$0.0505/kWh (\$)	Total Cost (\$)	Dried Corn Mass @ Moisture Content (kg @ %)	Cost per Corn Mass (\$/tonne)
2	137.88	16.11	153.99	28363 @ 12.60	5.43
3	137.34	16.11	153.45	28605 @ 11.90	5.36
TOTAL	275.22	32.22	307.44	56968 @ 12.25	
AVE					\$5.40/tonne @ 12.25% m.c.

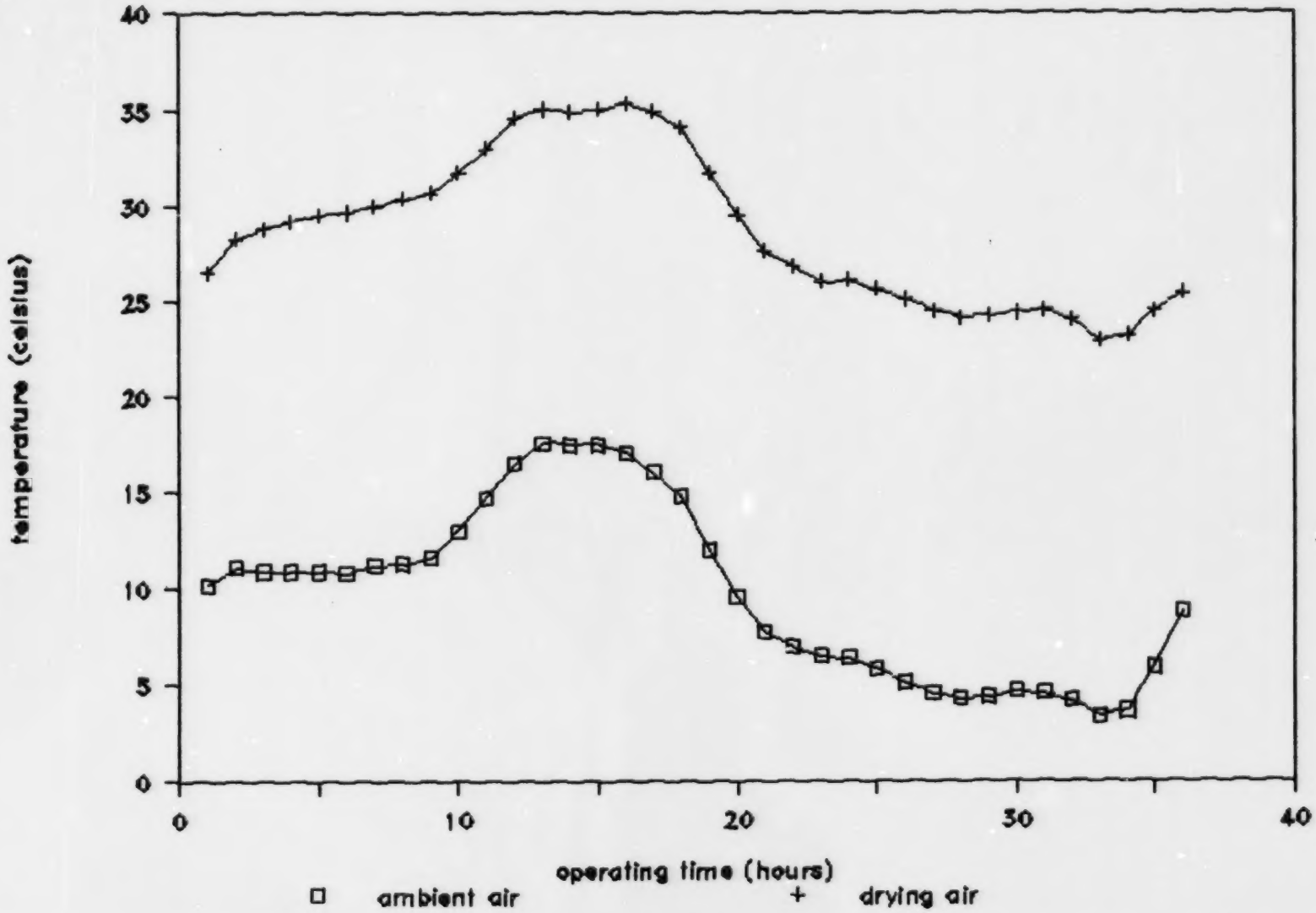

Figure 1C: Drying air and ambient air temperatures during drying of a single layer of corn 1400 to 1500 mm deep.

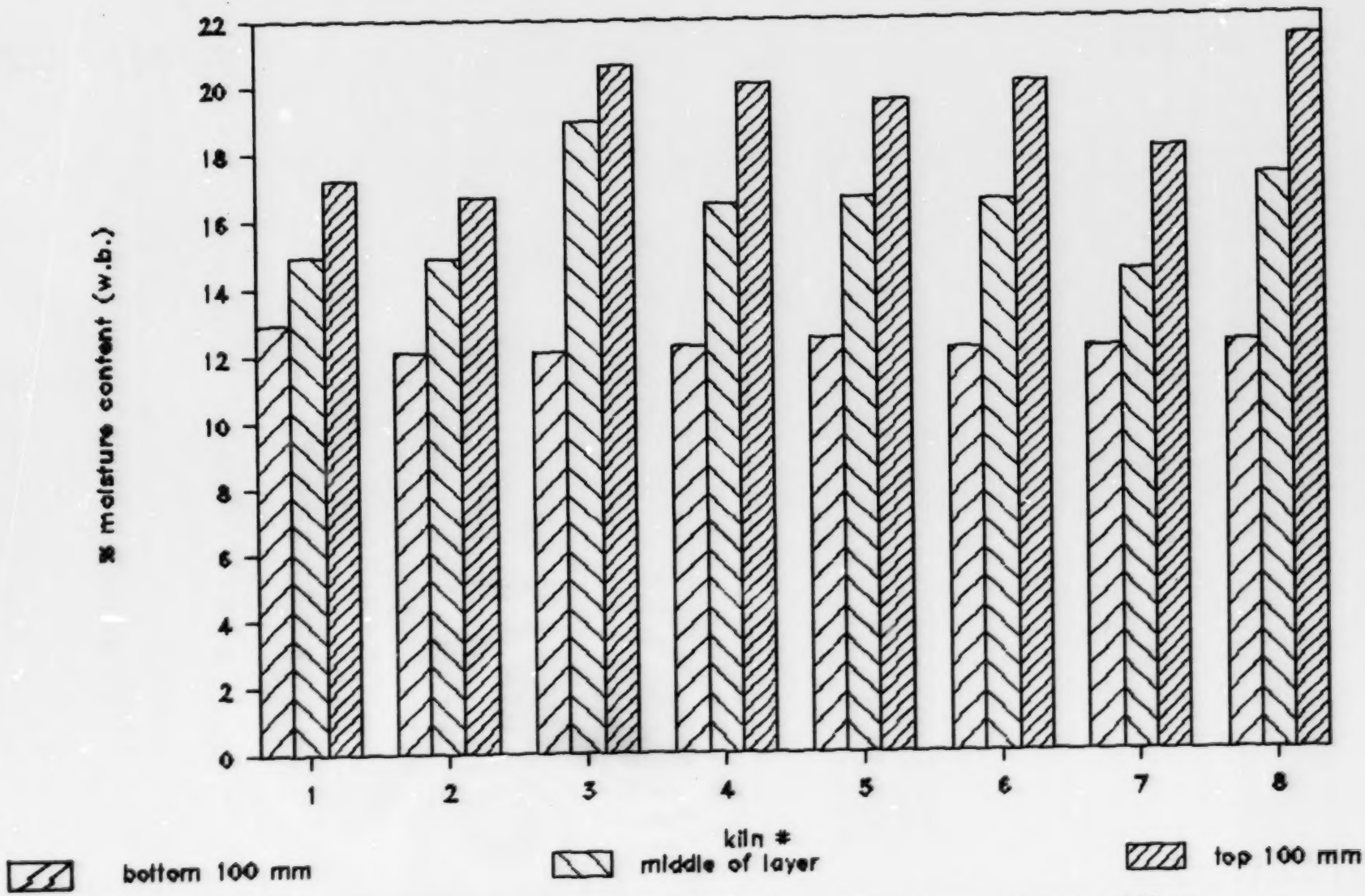

Figure 2C: Moisture contents at three locations in a layer of corn 650 to 850 mm deep.

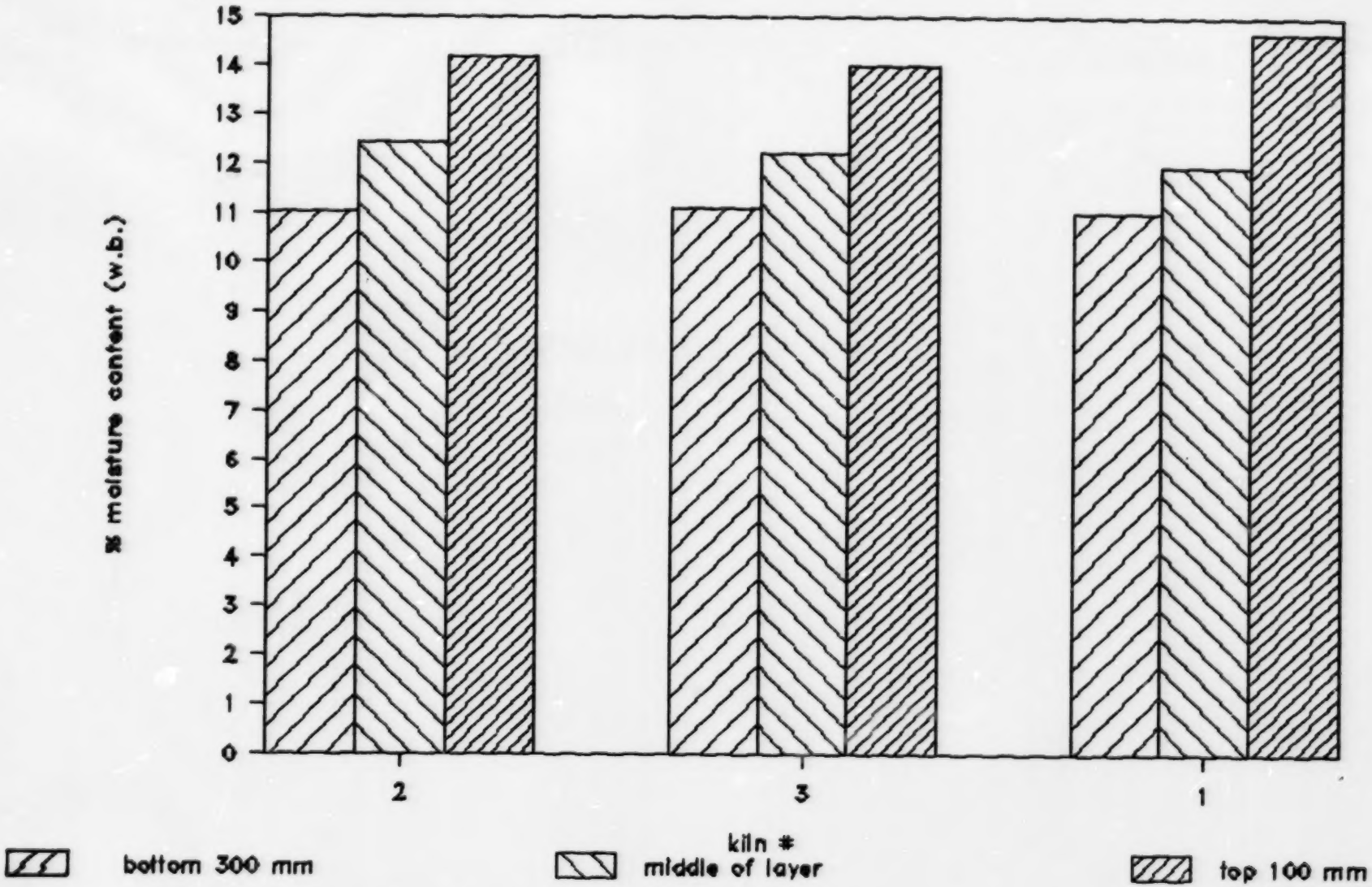

Figure 3C: Moisture contents at three locations in a layer of corn 1400 to 1500 mm deep (kiln #2 and 3) and two consecutive layers (kiln #1).

ii) EFFECTS OF AIRFLOW RATES IN RELATION TO CURING AND QUALITY OF PEANUTS

BACKGROUND

Commercial production of peanuts is relatively new to Ontario. The first commercial crop of peanuts was grown in 1980. Crop size was about 70 ha in 1980 and has gradually increased since then to about 300 ha in 1987.

In Ontario, peanuts are harvested at 55 to 65% moisture content (w.b.) and must be dried to a safe storage moisture content of 10% (w.b.) or less. As compared to curing procedures used by peanut growers in the south-eastern United States, Ontario grown peanuts must be dried from a higher initial moisture content. In the United States, peanuts are dug, windrowed and field dried to about 20 to 30% moisture content (w.b.) prior to mechanical drying. Field drying is not possible in Ontario because of the possibility of frost at night during the harvest season of late September and October. Green peanuts which are frozen will have an off-flavour and are not marketable. Thus, curing Ontario grown peanuts is more energy intensive than U.S. curing methods.

In the United States, the majority of peanuts are cured in specialized peanut driers. Many Ontario peanut growers cannot afford these driers and are using modified bulk tobacco kilns to cure peanuts.

During 1982 and 1983, the Agricultural Energy Centre, O.M.A.F., conducted an on-farm demonstration project which compared the energy efficiency of various tobacco curing structures to cure peanuts (see report entitled "Energy Efficiency of Peanut Drying Using Existing Tobacco Curing Structures, Agdex 143/736).

The project also investigated two different curing methods: 1) no recirculation of drying air during the entire curing process as compared to 2) no recirculation of drying air during the initial stages of curing followed by partial recirculation of drying air during the latter stages of curing.

Results from the project indicated that batch curing of peanuts in bulk tobacco kilns was the most energy efficient curing method (as compared to using other tobacco curing facilities). Peanuts cured in bulk tobacco kilns using the combination of no-recirculation during the initial stages of curing and partial recirculation during the latter stages of curing required about 12.8 megajoules (MJ) of energy in the form of natural gas and electricity per kilogram of in-shell peanuts.

The Alternate Crop Section at the Agriculture Canada Research Station, Delhi, Ontario, provides peanut growers with the following curing recommendations (1987).

Temperature Curing air temperature should not exceed 35°C. Temperatures above 35°C increase the proportion of off-flavoured and split peanuts.

Humidity Excessively low or high humidity curing air must be avoided. High humidity promotes mould formation, sprouting and off-flavour whereas low humidity promotes rapid drying and results in poor milling characteristics (ie. splits). When the ambient air relative humidity is 50% or greater, the air should not be heated by more than 10 to 20 C°. An ambient relative humidity below 50% requires no additional heat to the curing air. (However, in Ontario during late September and October, the relative humidity is usually greater than 50%).

Airflow Rate Curing peanuts @ 55 to 65% moisture content (w.b.) requires a blower capable of pushing a minimum of 500 litres per second per cubic metre ($L/s/m^3$) of peanuts. An airflow rate below 500 $L/s/m^3$ of peanuts decreases the drying rate and may allow moulds to develop which could result in off-flavours.

Ontario peanut growers are limiting the maximum curing air temperature to 30°C, which is 5 C° less than the recommended

temperature of 35°C. The majority of peanut growers are also limiting the temperature rise of the ambient air temperature to 20 C°. However, many are not obtaining a minimum airflow rate of 500 L/s/m^3 of peanuts.

Table 1P indicates the airflow rates measured during peanut curing in 180 rack size, "DeCloet" bulk tobacco kilns at a farm site in October of 1986. The measured airflow rate ranged from 264 to 319 L/s/m^3 of peanuts. This is about 35 to 50% less than the recommended airflow of 500 L/s/m^3 of peanuts.

The effects of airflow rates in relation to curing and quality of Ontario grown peanuts is not known. Literature from the United States suggests that to prevent the growth of mould which could result in off-flavours, a minimum of 500 L/s/m^3 of peanuts is required for peanuts at 50% moisture content (w.b.) or greater (Glover 1970).

Ontario peanut growers and processors have indicated that the quality (ie. taste and appearance) of peanuts cured in bulk tobacco kilns is generally good, however, not always consistent. A project was initiated to determine the effects of airflow rates of 500 L/s/m^3 of peanuts or less in relation to the curing and quality of Ontario grown peanuts.

OBJECTIVES

Project objectives were as follows:

a) determine the rate of drying (% moisture removal per hour) at airflow rates of 500 L/s/m^3 of peanuts or less;
b) determine the effects of airflow rates of 500 L/s/m^3 of peanuts or less in relation to peanut quality;
c) determine fuel energy requirements for curing peanuts at airflow rates of 500 L/s/m^3 of peanuts or less.

METHOD

Mini-Bulk Kiln Specifications

The project was conducted at the Agriculture Canada Research

Station, Delhi, Ontario. Nine "mini-bulk kilns" at the station were used for curing peanuts at different airflow rates (see figure 1P).

The mini-bulk kilns (mini-kilns) are basically of the same configuration as full-size bulk kilns, with one exception, the loading capacity of each mini-kiln is 1/75th that of a 150 rack bulk tobacco kiln. In addition, unlike most bulk tobacco kilns which are heated with natural gas or propane, the mini-kilns are heated with electricity. Each mini-kiln is equipped with a 2 stage, 3 kW electric resistance heater.

A "B Baby Vent" centrifugal blower powered by a 0.2 kW motor circulates the air within the mini-kilns in the same manner as in full-size bulk kilns. Air is forced into a lower plenum and up through a perforated metal floor. After the air has passed through the product (in this case peanuts) it either returns to the blower for recirculation or is expelled from the kiln through a pressure sensitive exhaust vent.

Airflow Rates

Each mini-kiln was used to cure peanuts at a different airflow rate. From the authors' previous experience using these kilns for curing peanuts, it was known that loading peanuts to a depth of 480 to 535 mm in the kilns results in an airflow of about 500 $L/s/m^3$ of peanuts (depending upon debris within peanuts). It was decided that increasing the peanut depth from 480 mm by increments of 55 mm would insure incremental decreases of the airflow rate.

The loading depth selected for each mini-kiln is indicated below:

KILN #	PEANUT DEPTH
1	480 mm
2	535 mm
3	590 mm
4	645 mm
5	700 mm
6	755 mm
7	810 mm
8	865 mm
9	920 mm

MONITORING

A "Kaye-Digi II" datalogger and type T thermocouples were used to record dry-and wet-bulb temperatures of the drying air in the lower plenum (before the curing air entered the peanuts) of each mini-kiln. Ambient air temperatures were recorded at the weather station of the Agriculture Canada Research Station, Delhi.

Airflow through the peanuts in each mini-kiln was measured daily using an "Alnor" velometer. The velometer covers an area of 350 mm x 350 mm and measures air velocity with a set of pitot tubes. The meter is calibrated to indicate the resultant airflow rate in cubic feet per minute.

Each mini-kiln is equipped with a kWh meter which measures the electrical consumption of the heater. The kWh meter readings were recorded daily during curing.

Initial moisture contents of the peanuts were determined using an oven dry method of 130°C for 7 hours. Final moisture contents of the peanuts were determined using a "Stienlite Model D" electronic moisture tester.

CURING PROCEDURE

The peanuts cured were of the Garroy variety and were harvested with a once-over harvester. The peanuts were not washed prior to curing (many Ontario growers wash the peanuts), thus plant debris and soil were cured as well. Curing commenced immediately after harvesting.

The curing schedule used was identical to that used by most Ontario peanut growers. Each kiln thermostat was set at 30°C. During curing the drying air temperature was not allowed to exceed the ambient air temperature by 20 C°. The loading doors of the mini-kilns remained open and the air return intakes to the blowers were blocked until the hulls of the peanuts at the top of the layer in each kiln were dry (at this point the

peanuts begin to rattle in the shell). At this time the return air intake to the blower was opened and the doors were closed until the completion of curing.

Moisture samples were taken daily after the doors were closed. When the moisture content decreased to 10% (w.b.) or less, the heater was turned off and the blower left on until the peanuts had cooled to the ambient air temperature.

Each kiln was filled to the preselected depth for each of four test cures. The cures began on the following dates:

Cure 1 - September 25/87;

Cure 2 - October 5/87;

Cure 3 - October 13/87;

Cure 4 - October 23/87.

RESULTS AND EVALUATION

Airflow Rate

The results of curing peanuts at different depths in the nine mini-kilns over the 4 cures is shown in table 2P. The initial moisture content of the peanuts over the 4 cures ranged from 61 to 68% (w.b.) while the dried moisture content of the peanuts ranged from 6 to 10% (w.b.).

Increasing the peanut depth from 480 mm to 920 mm by increments of 55 mm per kiln resulted in airflows from 645 L/s/m^3 down to 169 L/s/m^3 over the 4 cures. However, identical peanut depths during the 4 cures unfortunately did not result in comparable airflow rates. Figure 2P illustrates the variation in airflow rates at each depth over the 4 cures.

The variation in airflow rates at identical depths over the 4 cures can be attributed to the amount of debris contained amongst the peanuts. As shown in table 3P, significantly more debris was contained amongst peanut pods in cures 3 and 4 than in cures 1 and 2. The airflow rates measured during cure 3 were the lowest of the 4 cures while the majority of airflow rates measured during cure 4 were higher than cure 3 but lower than cures 1 and 2. It can be assumed that debris amongst peanut

pods increases the resistance to air which decreases airflow.

Drying Rate

There appears to be a trend that the length of time to cure the peanuts increased as the airflow rates were decreased (see table 2P). Comparing the length of time to cure the lowest depth of 480 mm to the deepest depth of 920 mm, the deepest depth of peanuts required 29.5 to 48.0 h longer over the 4 cures.

Figure 3P illustrates for cure 1 that decreasing the airflow rate decreased the drying rate (% moisture content reduced per hour, % m.c./h). The other 3 cures indicated a similar trend.

Table 4P shows the relationship between drying rate and the temperature rise of the ambient air during each cure. During cure 1 the drying rate ranged between 0.29% m.c./h at an airflow of 212 L/s/m^3 to 0.39% m.c./h at an airflow of 645 L/s/m^3. The drying rate during cures 2, 3 and 4 increased from a low of 0.35% m.c./h at 207 L/s/m^3 to a high of 0.49% m.c./h at 532 L/s/m^3. Even though the lower airflow rates during cures 2, 3 and 4 were similar to cure 1, the drying rate was at least 0.06% m.c./h faster. Similarly at the higher airflow rate of 532 L/s/m^3 which was 113 L/s/m^3 less than the airflow rate recorded during cure 1, the drying rate was 0.10% m.c./h faster.

The faster drying rates can probably be attributed to a cooler ambient temperature during cures 2, 3 and 4. The maximum temperature rise of the ambient air was between 14 and 15 C° during cure 1, whereas during cures 2, 3 and 4 it ranged from 16 to 21 C°. Thus, heating cooler ambient air during cures 2, 3 and 4 increased the drying potential of the air and increased the rate of drying as compared to cure 1.

Peanut Quality

Physical Characteristics: Table 5P shows the pnysical characteristics of peanuts cured in each of the mini-bulk kilns over the four cures. The total percentage of sound mature kernels

(referred to as SMK where the kernel size is greater than 5.95 mm) ranged from 44.5 to 53.4% for cure 1, 54.1 to 59.1% for cure 2, 52.4 to 55.5% for cure 3 and 36.8 to 54.3% for cure 4.

It should be noted that the % pick (weight of split, discoloured or mechanically damaged kernels expressed as a percentage of the total SMK weight) was considerably greater for cures 2, 3 and 4 as compared to cure 1. Unfortunately the pick from each cure was not divided to determine its composition.

Seed Viability: Four samples of 25 peanuts (SMK grade) from each cure were germinated to determine seed viability. Each sample was treated with Granox P.F.M. (a peanut fungicide consisting of captan and maneb) at a rate of 3.8 g/kg of peanuts. Each sample was placed in a petri dish containing 10 ml of water and placed in a Con Enviro growth chamber at 21°C and 100% relative humidity. Germination counts were conducted after 96 hours.

Table 6P shows the % seed viability of each cure. There does not appear to be any relationship between % seed viability and airflow. However, there does appear to be a difference in % seed viability when comparing different harvest dates. Peanuts harvested on October 23 for cure 4 had the lowest average germination of about 68% whereas peanuts harvested on September 25 for cure 1 had the highest average germination of about 83%. It would appear that as the harvesting season progressed the peanuts began to deteriorate and lost some of their viability.

Appearance and Flavour: A random shelled sample of the SMK grade was selected from each kiln. The samples were picked (visually) to remove discoloured, split and mechanically damaged peanuts. About 1000 g of peanuts from each sample was roasted in peanut oil at 150°C and afterwards 0.6 g of salt was applied to each sample.

A panel consisting of 20 people evaluated the appearance and flavour of the peanuts cured at the different airflow rates.

The following scale was used by the panel members to rate the peanuts according to appearance and flavour:

Appearance - Good, score of 3 points
Fair, score of 2 points
Poor, score of 1 point

Flavour - Excellent, score of 5 points
Very Good, score of 4 points
Good, score of 3 points
Fair, score of 2 points
Poor, score of 1 point

The appearance and flavour scores from peanuts cured at each airflow rate were accumulated and averaged. Table 7P shows the results. Generally the appearance and flavour of peanuts cured at different airflow rates were rated mostly between 2 and 3 points. In other words the appearance and flavour were considered fair to good.

Figures 4P to 7P illustrate the appearance and flavour ratings from each cure more clearly. Figure 4P, cure 1, does not indicate any significant effect on appearance and flavour of peanuts cured at different airflow rates. Figure 5P, cure 2, does indicate a slight relationship that at airflow rates of 284 $L/s/m^3$ or less the appearance and flavour increased. Figure 6P, cure 3, indicates again that there does not appear to be any relationship between airflow rates and appearance and flavour. However, it should be noted that airflow rates during cure 3 were 373 $L/s/m^3$ and less. Figure 7p, cure 4, indicates a slight increase in flavour at airflow rates of 363 $L/s/m^3$ or less, however, the appearance decreased at airflow rates of 426 $L/s/m^3$ or less.

Even though there is some evidence that airflow might effect appearance and taste, the composite results from the existing data does not indicate a well defined trend.

Fuel Energy Consumption In Relation to Airflow

Table 8P indicates fuel energy consumed at the different airflows during each cure. When comparing the fuel energy

consumed per kilogram of water removed during each cure, it appears that as the ambient air temperature decreased, the fuel energy consumed per kilogram of water removed increased. Results from cure 1 indicate that at airflow rates of 212 to 645 L/s/m^3 of peanuts about 5.4 to 8.2 MJ of energy was consumed per kilogram of water removed. During cure 4, when the ambient air temperature was cooler, energy consumption increased to between 8.7 and 15.1 MJ per kilogram of water removed at airflow rates from 207 to 532 L/s/m^3 of peanuts.

Figures 8P to 11P illustrate more clearly the fuel energy consumed per kilogram of water removed at the different airflows during each cure. Figures 8p and 9p do not indicate any relationship between energy consumption and airflow. Figures 10P and 11P give a slight indication that at the higher airflow rates more energy was consumed.

CONCLUSIONS

1.) Decreasing the airflow rate below 500 L/s/m^3 of peanuts increases the length of time to cure peanuts.
2.) Debris amongst peanut pods increases air resistance and decreases airflow.
3.) The appearance and flavour of peanuts cured at airflow rates ranging from 169 L/s/m^3 to 645 L/s/m^3 was not significantly affected.
4.) The drying rate of peanuts increases as the ambient air temperature decreases.
5.) Energy consumption required to cure peanuts increases as the ambient air temperature decreases.

RECOMMENDATIONS

The project should be continued in 1988 to verify the 1987 year's results. In addition, the project should be expanded to investigate the effects of different temperature rises of the ambient air in relation to cured peanut quality.

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Van Hooren D. L. and Columbus M. 1983. Energy efficiency of peanut drying using existing tobacco curing structures. Energetics. Agricultural Energy Centre, Ontario Ministry of Agriculture and Food, Guelph, Ontario. 33pp.

TABLE 1P: Airflow rates recorded during peanut curing in 180 rack size, "DeCloet", bulk kilns

KILN #	LOADING DEPTH (mm)	VOLUME OF PEANUTS (m^3)	AIRFLOW* (L/s)	AIRFLOW RATE ($L/s/m^3$)
1	470	17.07	4510	264
2	520	18.88	6030	319
3	520	18.88	5170	274
4	550	19.97	5950	298
5	580	21.06	5645	268

AIRFLOW* - An "Alnor" velometer was used to measure airflow. The velometer covers an area of about 350 mm x 350 mm and measures the velocity with a set of pitot tubes. The meter is calibrated to indicate the result as an airflow rate in cubic feet per minute. The velometer was placed on top of the peanut layer in 5 bulk kilns and the airflow exiting the peanut layer was recorded (converted to L/s).

TABLE 2P: Peanut curing data

CURE #	KILN #	PEANUT DEPTH mm	INITIAL M.C. (% w.b.)	FINAL M.C. (% w.b.)	CURE LENGTH NO-RECIRC. (h)	CURE LENGTH RECIRC. (h)	CURE LENGTH TOTAL (h)	RATE OF DRYING (% m.c./h)	AIRFLOW RATE (L/s/m³)
1	1	480	67.95	7.0C	36.0	122.0	158.0	C.39	645
	2	535	67.95	6.70	45.0	135.0	180.0	C.34	504
	3	590	67.95	6.5C	61.0	119.0	180.0	0.34	496
	4	645	67.95	6.52	61.0	120.0	181.0	C.34	367
	5	700	67.95	7.02	69.0	121.5	190.5	0.32	319
	6	755	67.95	6.70	84.5	106.0	190.5	0.32	309
	7	810	67.95	6.90	84.5	121.5	206.0	C.30	281
	8	865	67.95	6.0C	84.5	121.5	206.0	C.30	275
	9	920	67.95	7.6E	94.0	112.0	206.0	C.29	212
2	1	480	60.65	8.70	41.5	72.5	114.0	C.46	586
	2	535	60.6E	9.36	41.5	72.5	114.0	C.4E	472
	3	590	60.6E	9.6E	41.5	72.5	114.0	C.4E	452
	4	645	60.6E	9.54	41.5	79.8	121.3	0.42	357
	5	700	60.6E	8.24	49.5	88.3	137.8	0.38	284
	6	755	60.6E	9.45	49.5	88.3	137.8	0.37	291
	7	810	E0.65	8.8E	49.5	88.3	137.8	0.38	257
	8	865	60.65	8.24	41.5	96.3	137.8	0.38	280
	9	920	60.65	9.36	65.0	78.5	143.5	0.36	188
3	1	480	63.51	9.5C	41.5	73.5	115.0	C.47	373
	2	535	63.51	8.68	41.5	81.5	123.0	0.4E	384
	3	590	63.51	8.56	50.7	87.3	138.0	C.4C	278
	4	645	63.51	9.74	50.7	71.3	122.0	C.44	317
	5	700	63.51	8.56	50.7	87.3	138.0	0.4C	275
	6	755	63.51	9.76	66.0	81.0	147.0	C.37	194
	7	810	E3.51	9.46	66.0	72.0	138.0	C.39	189
	8	865	63.51	9.80	66.0	72.0	138.0	C.39	240
	9	920	63.51	9.46	74.5	72.5	147.0	C.37	169
4	1	480	67.16	8.8E	46.0	73.0	119.0	C.49	532
	2	535	67.16	9.22	46.0	73.0	119.0	C.49	448
	3	590	67.16	8.80	46.0	82.5	128.5	C.45	426
	4	645	67.16	9.10	46.0	80.3	126.3	0.46	363
	5	700	67.16	8.68	54.7	87.8	142.5	0.41	322
	6	755	67.16	9.0C	79.0	71.3	150.3	0.39	229
	7	810	E7.16	9.18	92.5	73.3	165.8	0.35	224
	8	865	67.16	9.20	68.5	82.1	150.6	0.38	255
	9	920	67.16	8.72	79.0	86.5	165.5	0.35	207

TABLE 3P: Debris contained within peanut pods

DATE	CURE #	KILN #	PEANUT POD AND DEBRIS WT. (kg)	DEBRIS WT. (kg)	DEBRIS WT. PER TOTAL POD WT. (%)
Sept. 25	1	1	38.6	1.4	3.6
		2	35.4	1.2	3.4
		3	38.8	1.4	3.6
		4	32.0	1.4	4.4
		5	45.8	1.3	2.8
		6	49.4	1.5	3.0
		7	58.1	0.7	1.2
		8	60.3	0.9	1.5
		9	64.0	2.1	3.3
Oct. 5	2	1	31.3	2.0	6.4
		2	34.0	1.8	5.3
		3	41.7	1.1	2.6
		4	46.3	1.4	3.0
		5	47.4	1.6	3.4
		6	52.8	1.5	2.8
		7	55.3	2.0	3.6
		8	62.1	2.5	4.0
		9	63.5	2.3	3.6
Oct. 13	3	1	40.4	9.3	23.0
		2	37.4	9.5	25.4
		3	49.2	15.9	32.3
		4	51.7	8.4	16.2
		5	51.5	6.8	13.2
		6	59.9	8.6	14.4
		7	62.6	12.9	20.6
		8	68.0	8.8	12.9
		9	71.0	10.7	15.1
Oct. 23	4	1	29.9	6.1	20.4
		2	29.5	8.4	28.5
		3	40.6	6.4	15.8
		4	46.7	8.1	17.3
		5	47.4	6.8	14.3
		6	54.4	12.0	22.1
		7	61.7	16.1	26.1
		8	64.9	13.0	20.0
		9	67.6	14.5	21.4

TABLE 4P: Drying rate as compared to temperature rise of ambient air

DATE	CURE #	KILN #	AIRFLOW RATE ($L/s/m^3$)	DRYING RATE (% m.c./h)	TEMPERATURE RISE ABOVE AMBIENT MINIMUM (C°)	MAXIMUM (C°)
Sept. 25	1	1	645	0.39	2.2	14.7
		2	504	0.34	1.9	14.4
		3	496	0.34	2.1	14.6
		4	367	0.34	1.9	14.4
		5	319	0.32	2.3	14.8
		6	309	0.32	2.3	14.8
		7	281	0.30	2.2	14.7
		8	275	0.30	2.6	15.1
		9	212	0.29	2.1	14.6
Oct. 5	2	1	586	0.46	5.9	17.1
		2	472	0.45	5.8	16.9
		3	452	0.45	6.3	17.4
		4	357	0.42	6.9	16.4
		5	284	0.38	6.2	17.3
		6	291	0.37	5.9	17.1
		7	257	0.38	6.2	17.7
		8	280	0.38	6.6	17.7
		9	188	0.36	6.1	17.2
Oct. 13	3	1	373	0.47	5.6	18.9
		2	384	0.45	5.7	19.0
		3	278	0.40	5.8	19.1
		4	317	0.44	5.8	19.1
		5	275	0.40	5.9	19.2
		6	194	0.37	5.4	N.R.
		7	189	0.39	5.9	19.2
		8	240	0.39	6.1	19.3
		9	169	0.37	5.9	19.2
Oct. 23	4	1	532	0.49	9.8	20.3
		2	448	0.49	9.5	20.0
		3	426	0.45	10.2	20.7
		4	363	0.46	9.6	20.2
		5	322	0.41	9.6	20.1
		6	229	0.39	9.7	20.3
		7	224	0.35	9.4	20.0
		8	255	0.38	9.4	19.9
		9	207	0.35	9.4	20.0

TABLE 5P: Physical characteristics of peanuts cured.

DATE	CURE #	KILN #	CLEAN POD WT. (g)	SHELL[1] OUT (%)	TOTAL[2] SMK (%)	OIL[3] (%)	PICK[4] (%)
Sept. 25	1	1	1373.3	56.9	47.4	9.5	10.1
		2	1352.9	58.0	50.3	7.7	10.3
		3	1138.8	58.1	47.6	10.5	13.5
		4	1466.0	61.3	50.8	10.5	11.5
		5	1315.5	53.9	44.5	9.4	11.7
		6	1370.5	58.7	50.8	7.9	10.7
		7	1187.1	59.5	50.9	8.6	13.3
		8	1191.9	61.6	53.3	8.3	9.6
		9	1191.9	62.3	53.4	8.9	13.0
Oct. 5	2	1	1023.0	64.9	54.1	10.8	31.5
		2	1058.0	66.5	57.0	9.5	24.4
		3	1096.2	67.2	57.9	9.3	26.9
		4	1299.1	67.5	58.1	9.4	26.3
		5	1136.4	66.7	58.9	7.8	19.0
		6	1335.7	66.0	54.3	11.7	31.4
		7	1112.5	66.6	57.3	9.3	28.2
		8	1123.9	68.2	59.1	9.1	28.7
		9	1474.0	67.7	58.9	8.8	19.0
Oct. 13	3	1	1099.5	65.6	55.0	10.6	21.4
		2	1091.1	64.1	52.6	11.5	12.9
		3	980.7	64.7	53.7	11.0	15.5
		4	1285.1	63.6	53.3	10.3	21.4
		5	1144.7	65.1	54.4	10.7	21.1
		6	1162.3	64.2	52.4	11.8	20.2
		7	1263.0	66.6	55.5	11.1	15.6
		8	1090.8	65.9	55.0	10.9	23.1
		9	1156.5	64.5	52.7	11.8	27.9
Oct. 23	4	1	1007.6	50.6	36.8	13.8	27.7
		2	1171.3	60.1	48.6	11.5	32.4
		3	1293.9	62.8	51.4	11.4	23.6
		4	1339.1	64.2	53.9	10.3	26.8
		5	1360.8	64.2	53.2	11.0	24.2
		6	1113.9	55.9	43.9	12.0	38.2
		7	1145.9	54.3	43.2	11.1	35.0
		8	1212.8	63.8	53.6	10.2	34.7
		9	1338.0	64.2	54.3	9.9	26.3

[1] shell out % - total weight of kernels expressed as percentage of total clean pod weight

[2] total SMK % - kernels greater than 5.95 mm expressed as percentage of total clean pod weight

[3] oil % - kernels less than 5.95 mm which are suitable for crushing for oil expressed as percentage of total clean pod weight

[4] pick % - weight of split, discoloured or mechanically damaged kernels expressed as a percentage of the total SMK weight

TABLE 6P: Seed viability

DATE	CURE #	KILN #	AIRFLOW RATE ($L/s/m^3$)	GERMINATION (%)
Sept. 25	1	1	645	75
		2	504	82
		3	496	89
		4	367	81
		5	319	89
		6	309	81
		7	281	80
		8	275	88
		9	212	84
Oct. 5	2	1	586	65
		2	472	70
		3	452	79
		4	357	87
		5	284	72
		6	291	67
		7	257	83
		8	280	81
		9	188	70
Oct. 13	3	1	373	73
		2	384	74
		3	278	76
		4	317	81
		5	275	73
		6	194	81
		7	189	76
		8	240	75
		9	169	77
Oct. 23	4	1	532	54
		2	448	62
		3	426	62
		4	363	80
		5	322	66
		6	229	61
		7	224	63
		8	255	83
		9	207	80

TABLE 7P: Appearance and flavour scores

DATE	CURE #	KILN #	AIRFLOW RATE (L/s/m³)	RATE OF DRYING (% m.c./h)	PANEL RATING	
					APPEARANCE (max. score 3)	FLAVOUR (max. score 5)
Sept. 25	1	1	645	0.39	2.10	2.75
		2	504	0.34	2.85	3.05
		3	496	0.34	2.20	3.15
		4	367	0.34	2.65	3.20
		5	319	0.32	2.60	2.60
		6	309	0.32	2.45	3.10
		7	281	0.30	2.50	3.00
		8	275	0.30	1.95	2.35
		9	212	0.29	2.60	2.70
Oct. 5	2	1	586	0.46	1.90	1.75
		2	472	0.45	2.05	2.10
		3	452	0.45	1.85	2.35
		4	357	0.42	2.10	2.15
		5	284	0.38	2.60	2.75
		6	291	0.37	2.15	2.55
		7	257	0.38	2.35	2.85
		8	280	0.38	2.40	3.05
		9	188	0.36	2.40	2.55
Oct. 13	3	1	373	0.47	2.50	2.10
		2	384	0.45	2.55	2.75
		3	278	0.40	2.55	2.45
		4	317	0.44	2.40	2.70
		5	275	0.40	2.80	2.75
		6	194	0.37	2.60	2.50
		7	189	0.39	2.55	2.55
		8	240	0.39	2.65	1.90
		9	169	0.37	2.80	2.35
Oct. 23	4	1	532	0.49	2.65	2.60
		2	448	0.49	2.35	2.70
		3	426	0.45	1.70	2.70
		4	363	0.46	2.10	3.10
		5	322	0.41	2.10	2.95
		6	229	0.39	2.45	3.30
		7	224	0.35	2.20	2.80
		8	255	0.38	2.60	3.25
		9	207	0.35	2.15	3.00

TABLE 8P: Fuel energy consumption

CURE	KILN #	AIRFLOW RATE ($L/s/m^3$)	FUEL USAGE (kWh)	H_2O REMOVED (kg)	FUEL ENERGY PER H_2O REMOVED (MJ/kg)
1	1	645	107	70.7	5.4
	2	504	117	65.4	6.4
	3	496	120	71.7	6.0
	4	367	133	58.7	8.2
	5	319	165	84.6	7.0
	6	309	147	91.5	5.8
	7	281	168	109.3	5.5
	8	275	197	114.8	6.2
	9	212	198	116.4	6.1
2	1	586	114	38.7	10.6
	2	472	104	42.0	8.9
	3	452	106	52.6	7.3
	4	357	118	58.3	7.3
	5	284	159	61.0	9.4
	6	291	137	66.7	7.4
	7	257	143	70.1	7.3
	8	280	165	79.4	7.5
	9	188	192	79.8	8.7
3	1	373	144	46.0	11.3
	2	384	124	41.9	10.7
	3	278	147	50.1	10.6
	4	317	138	63.8	7.8
	5	275	159	67.3	8.5
	6	194	158	75.6	7.5
	7	189	170	73.6	8.3
	8	240	182	87.1	7.5
	9	169	204	89.3	8.2
4	1	532	166	42.2	14.2
	2	448	156	37.2	15.1
	3	426	155	60.8	9.2
	4	363	164	68.2	8.7
	5	322	201	72.3	10.0
	6	229	224	75.1	10.7
	7	224	256	80.5	11.4
	8	255	235	91.6	9.2
	9	207	269	94.5	10.2

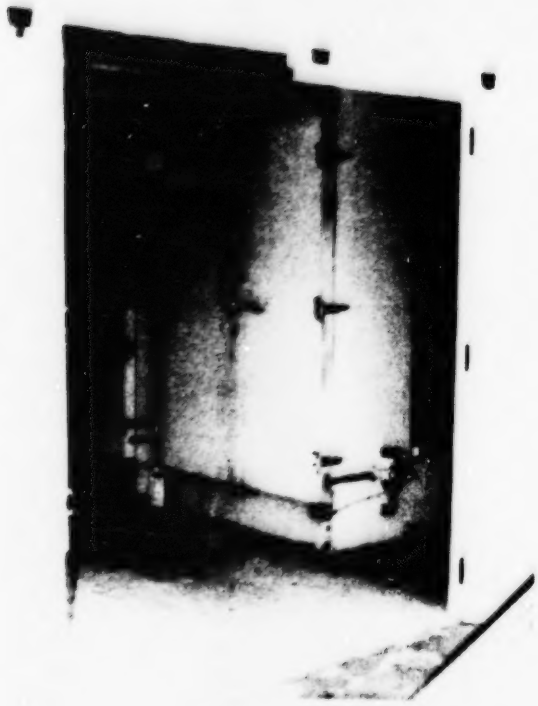

Figure 1P: Mini-bulk kilns used for curing peanuts.

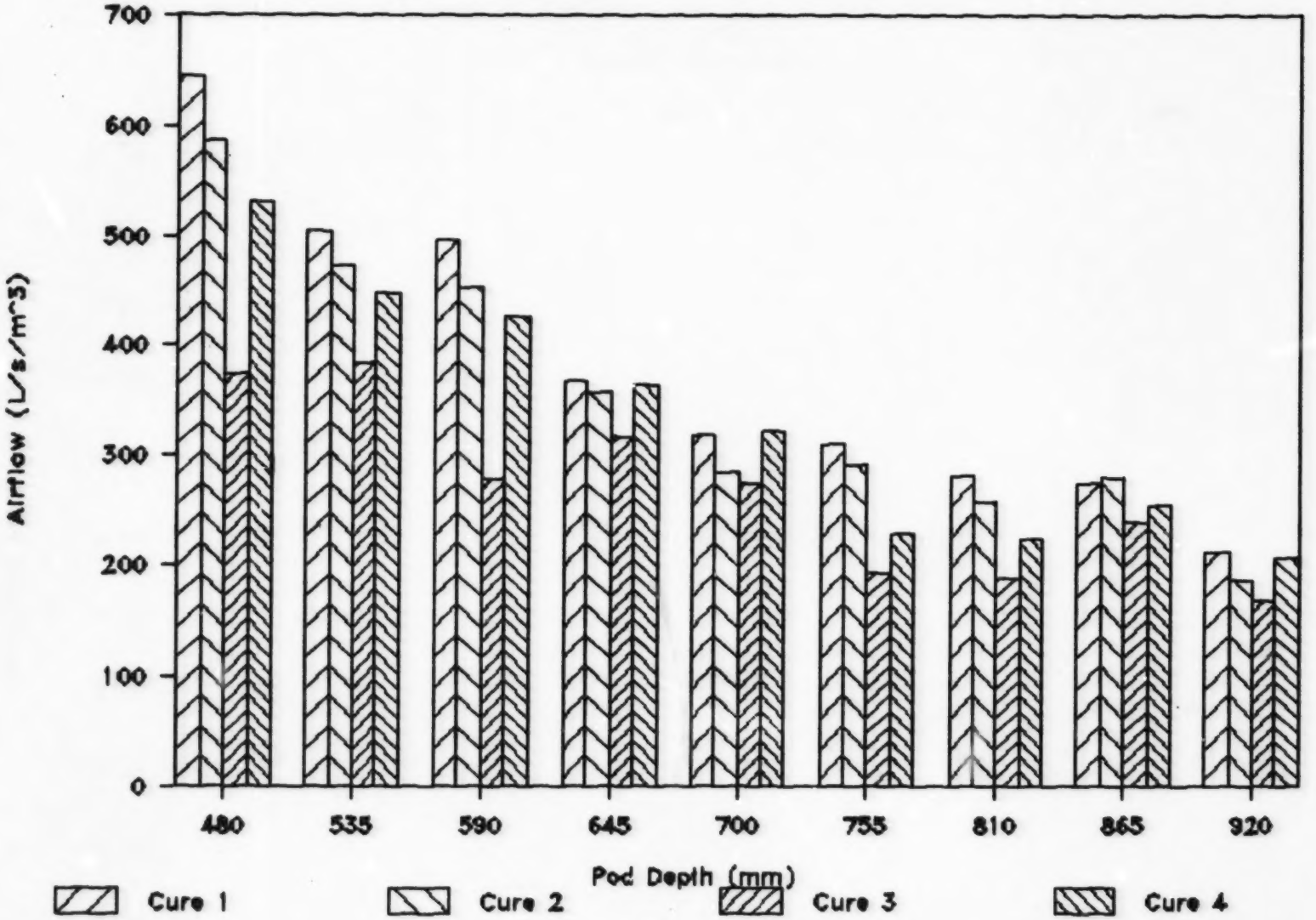

Figure 2P: Airflow rates at different peanut depths over the four cures

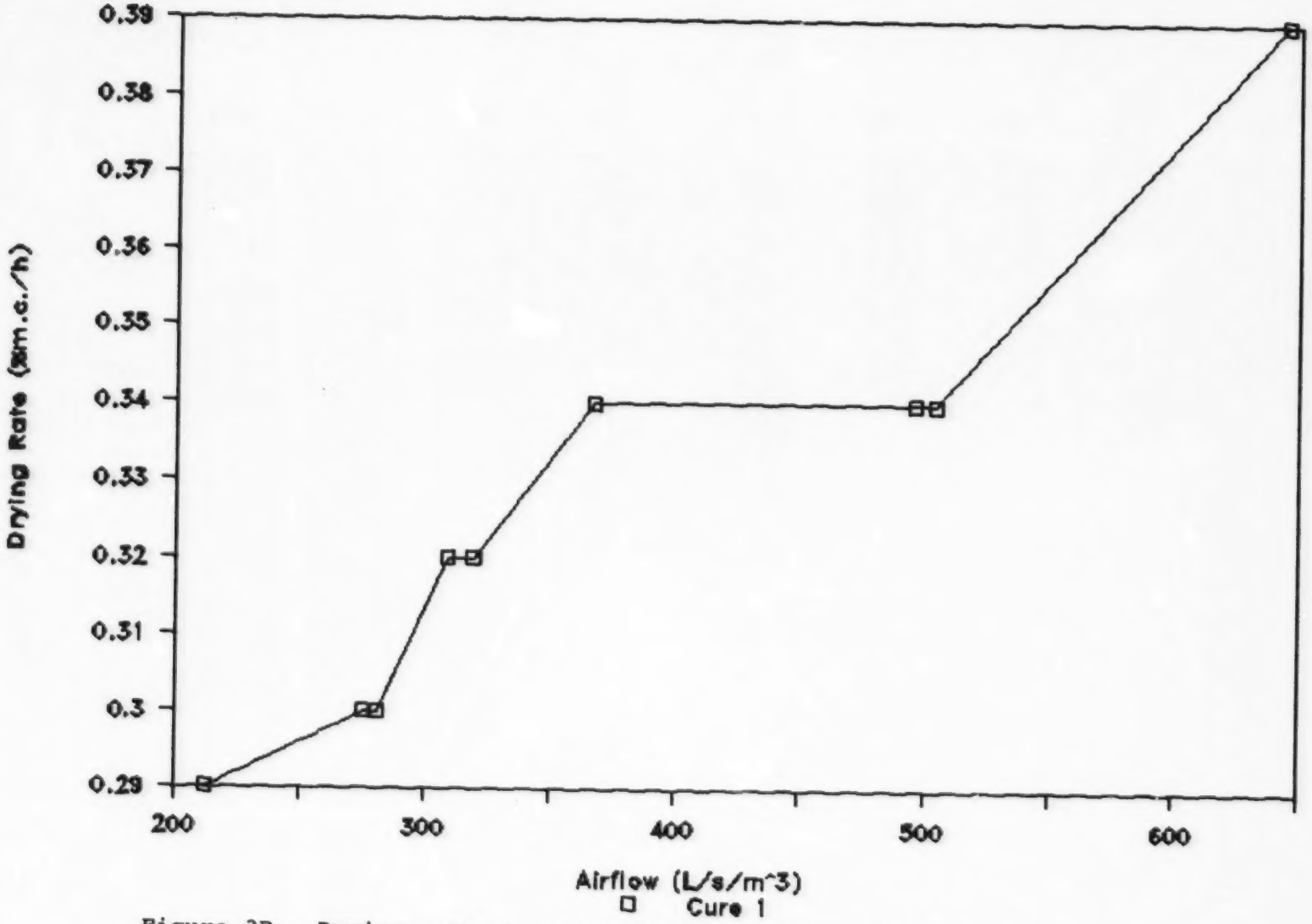

Figure 3P: Drying rate as compared to airflow rate from cure 1

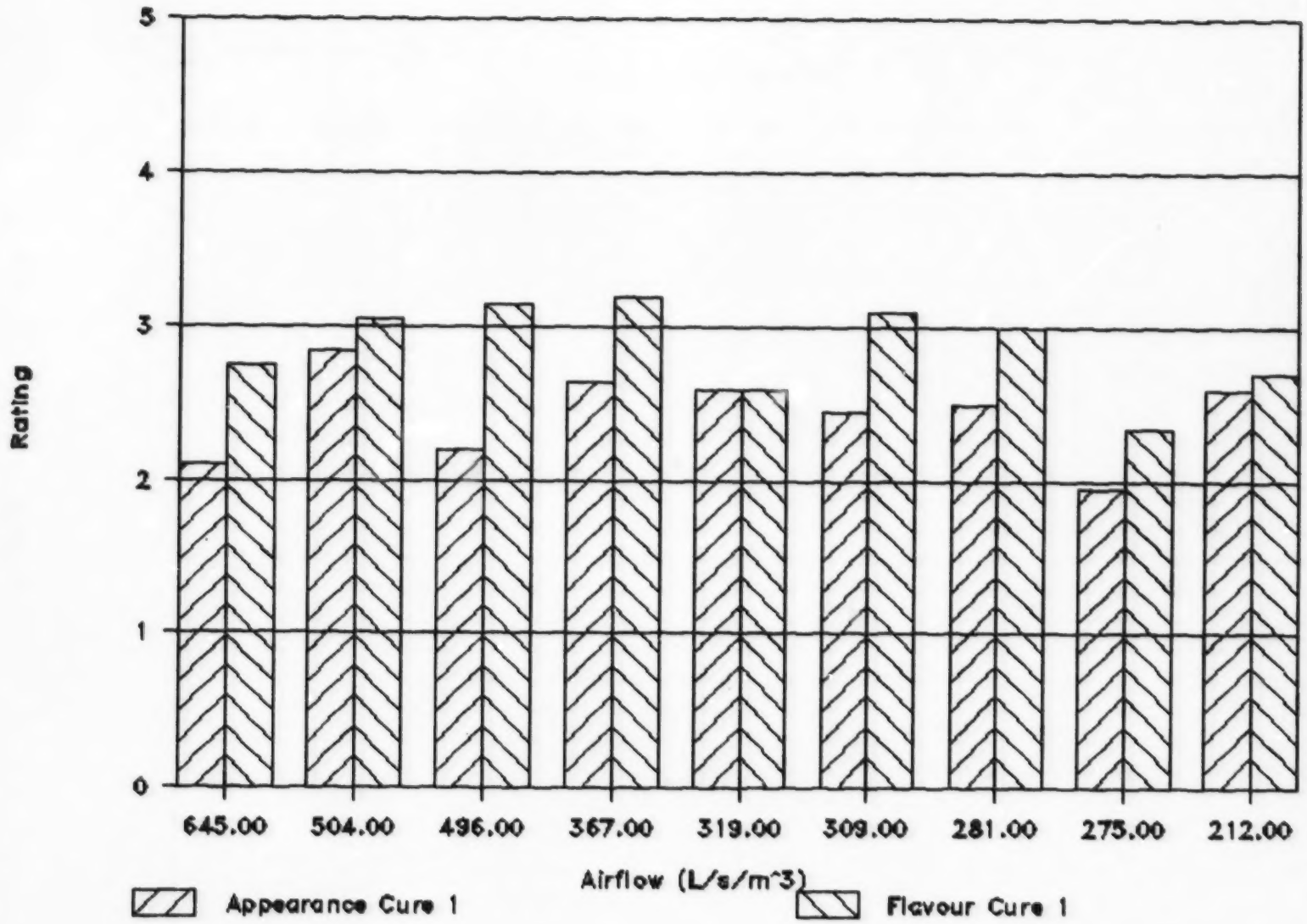

Figure 4P: Appearance and flavour ratings from cure 1

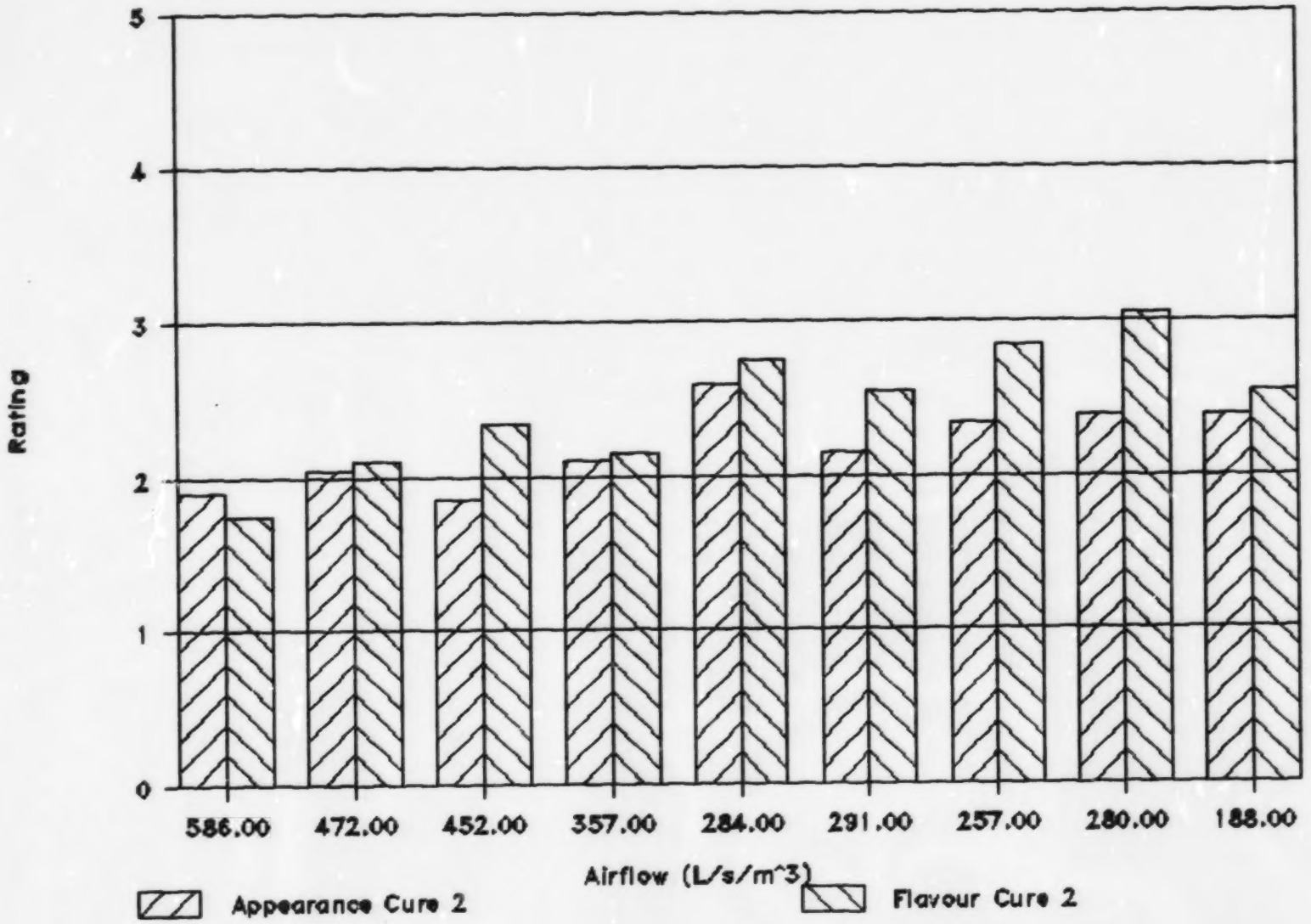

Figure 5P: Appearance and flavour ratings from cure 2

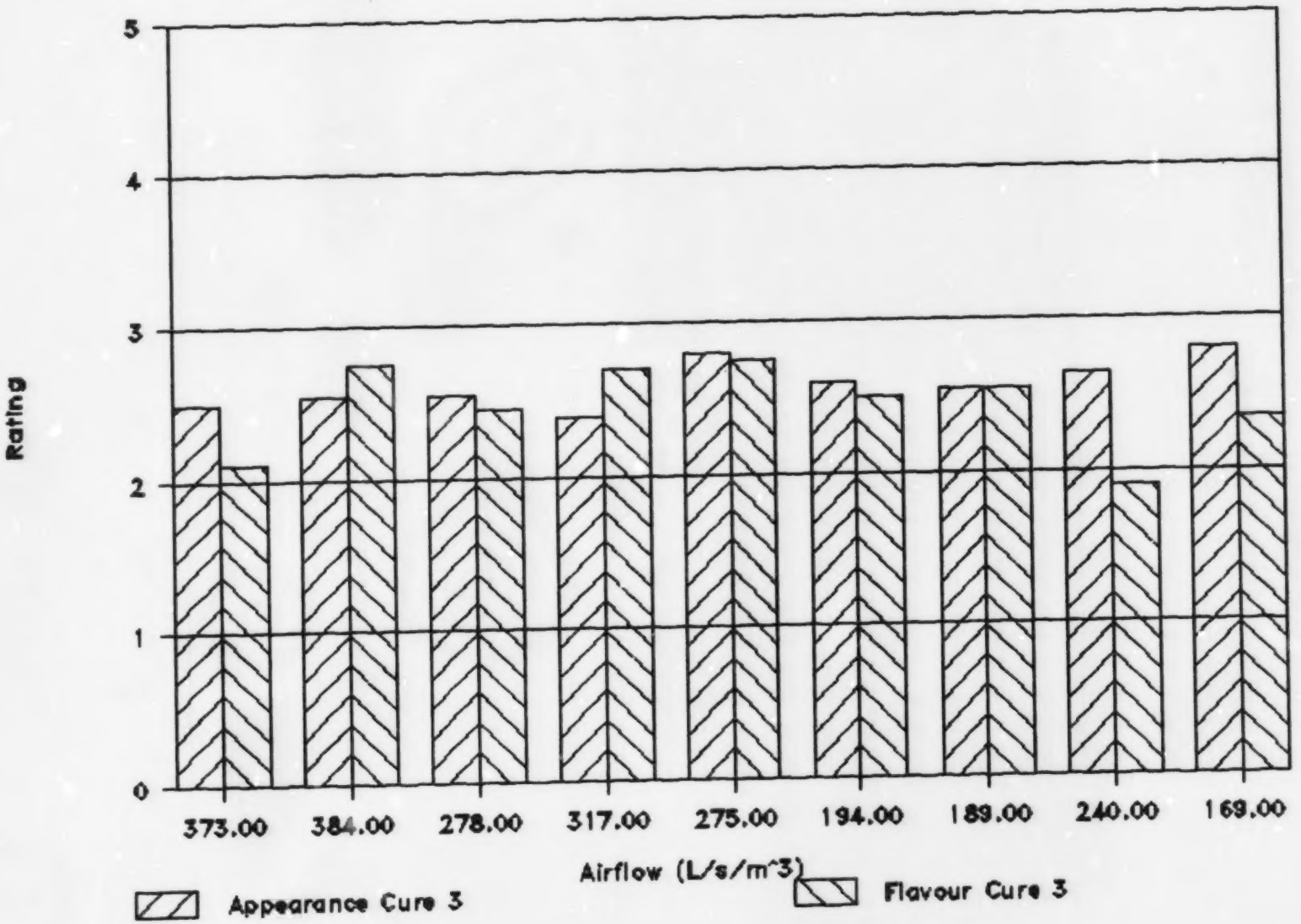

Figure 6P: Appearance and flavour ratings from cure 3

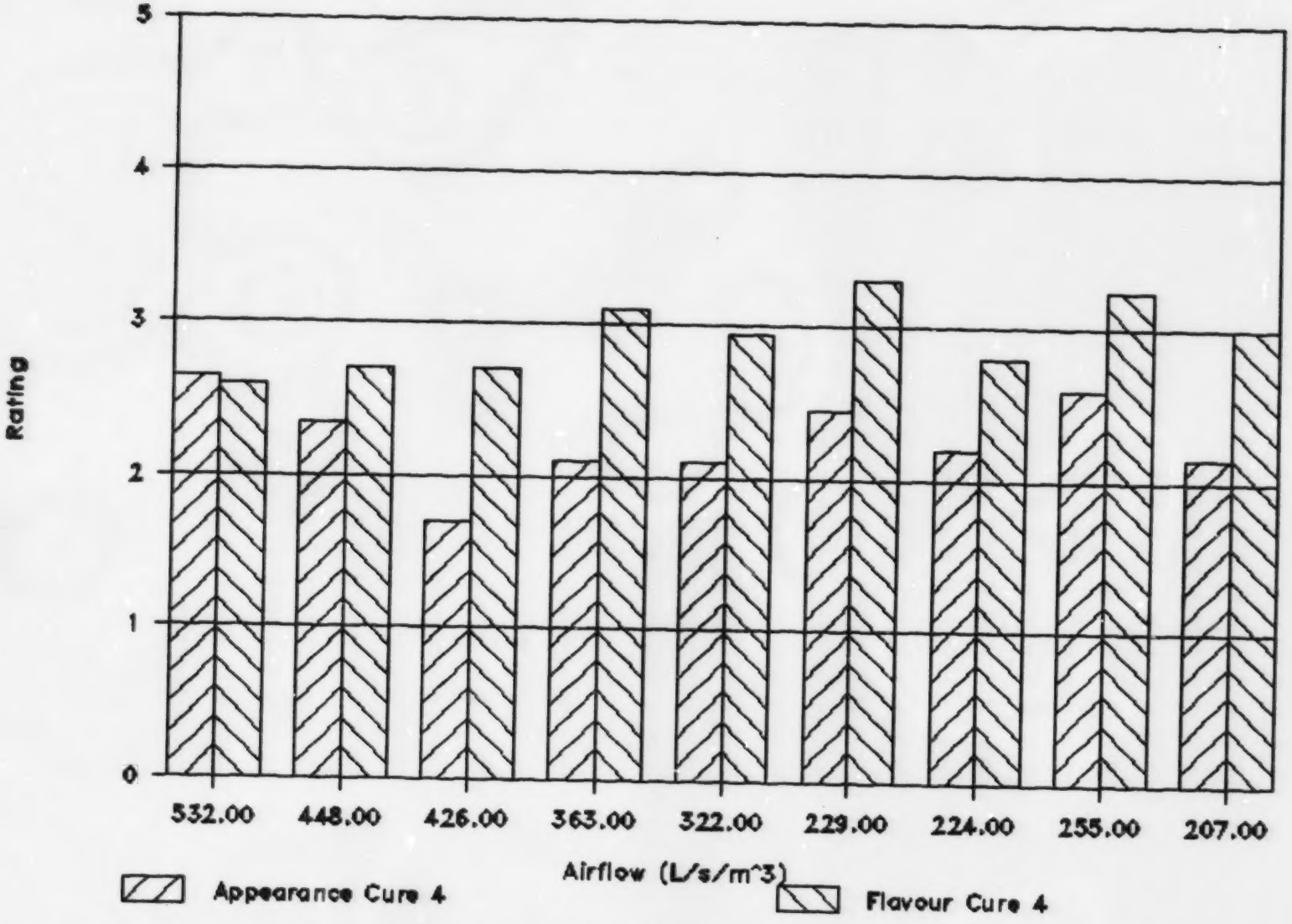

Figure 7P: Appearance and flavour ratings from cure 4

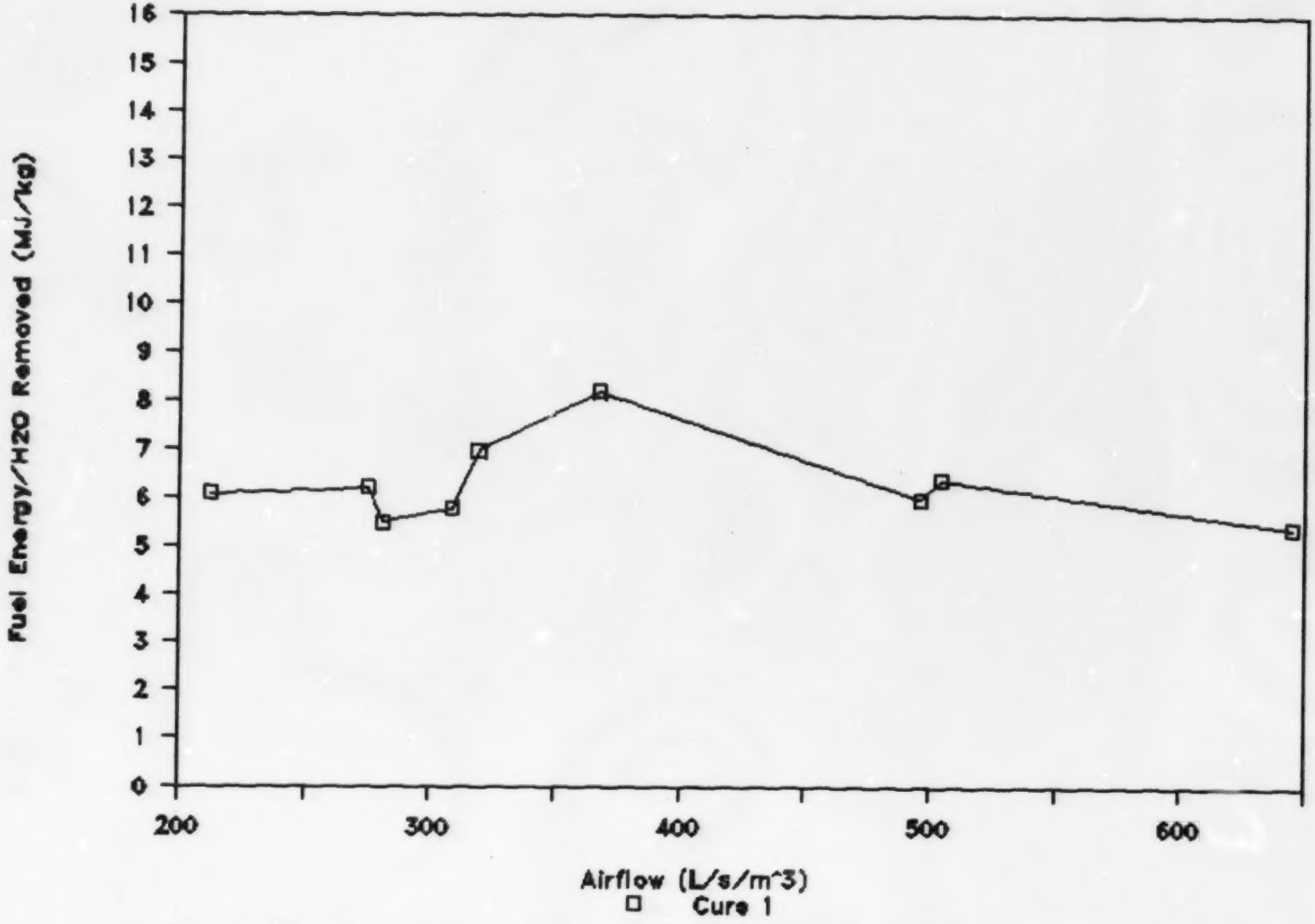

Figure 8P: Fuel energy consumed per kilogram of water removed at different airflow rates over cure 1

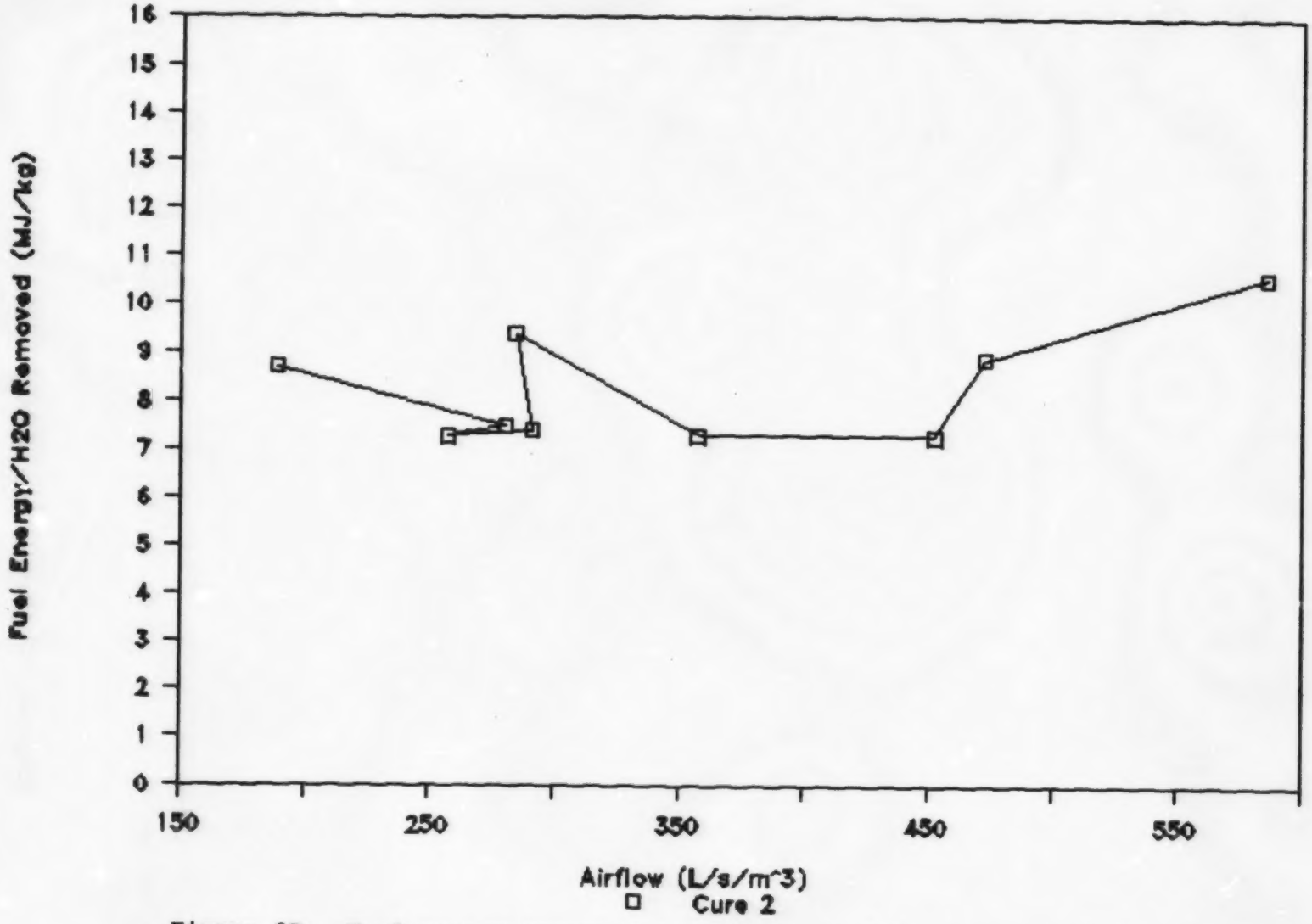

Figure 9P: Fuel energy consumed per kilogram of water removed at different airflow rates over cure 2

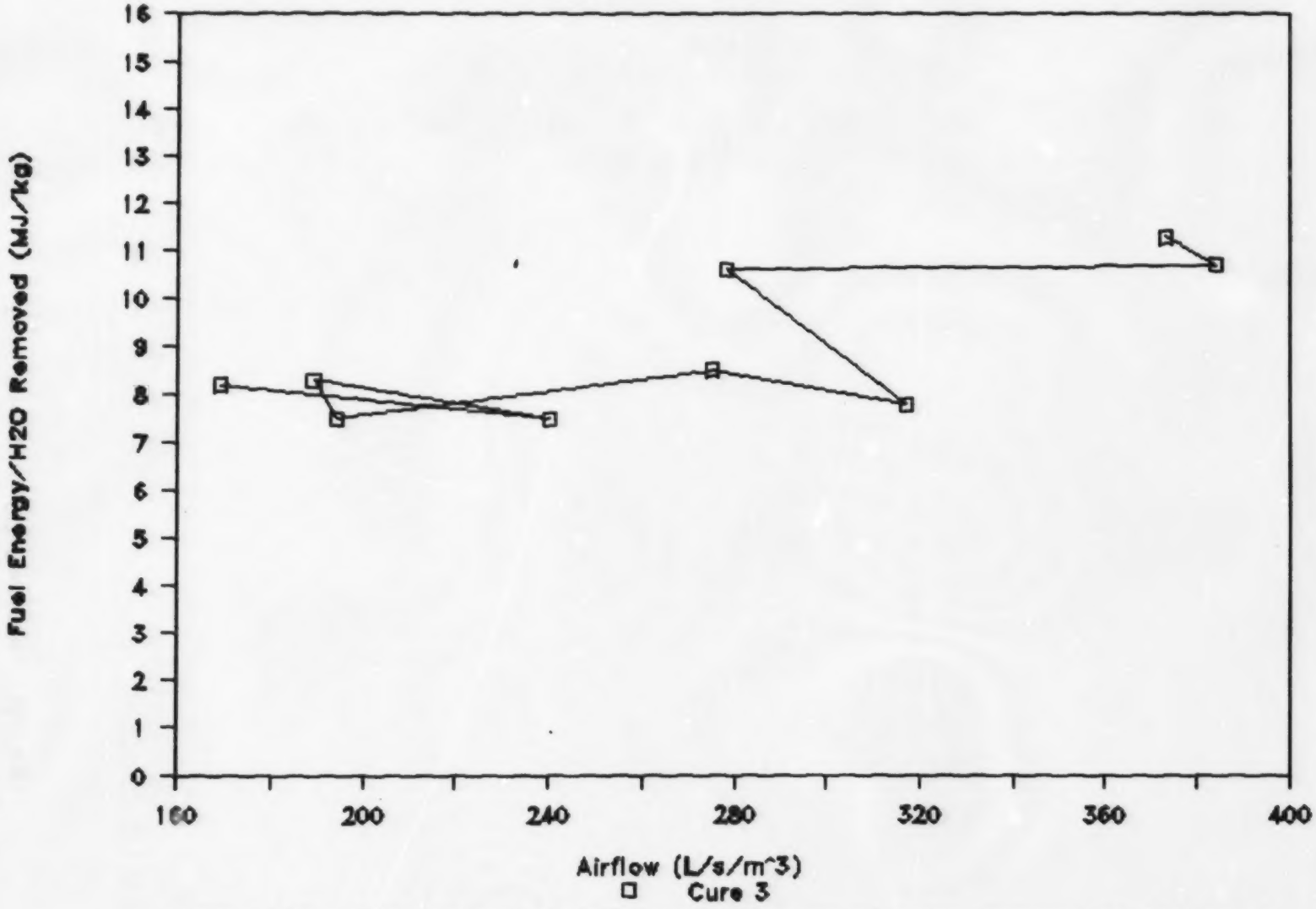

Figure 10P: Fuel energy consumed per kilogram of water removed at different airflow rates over cure3

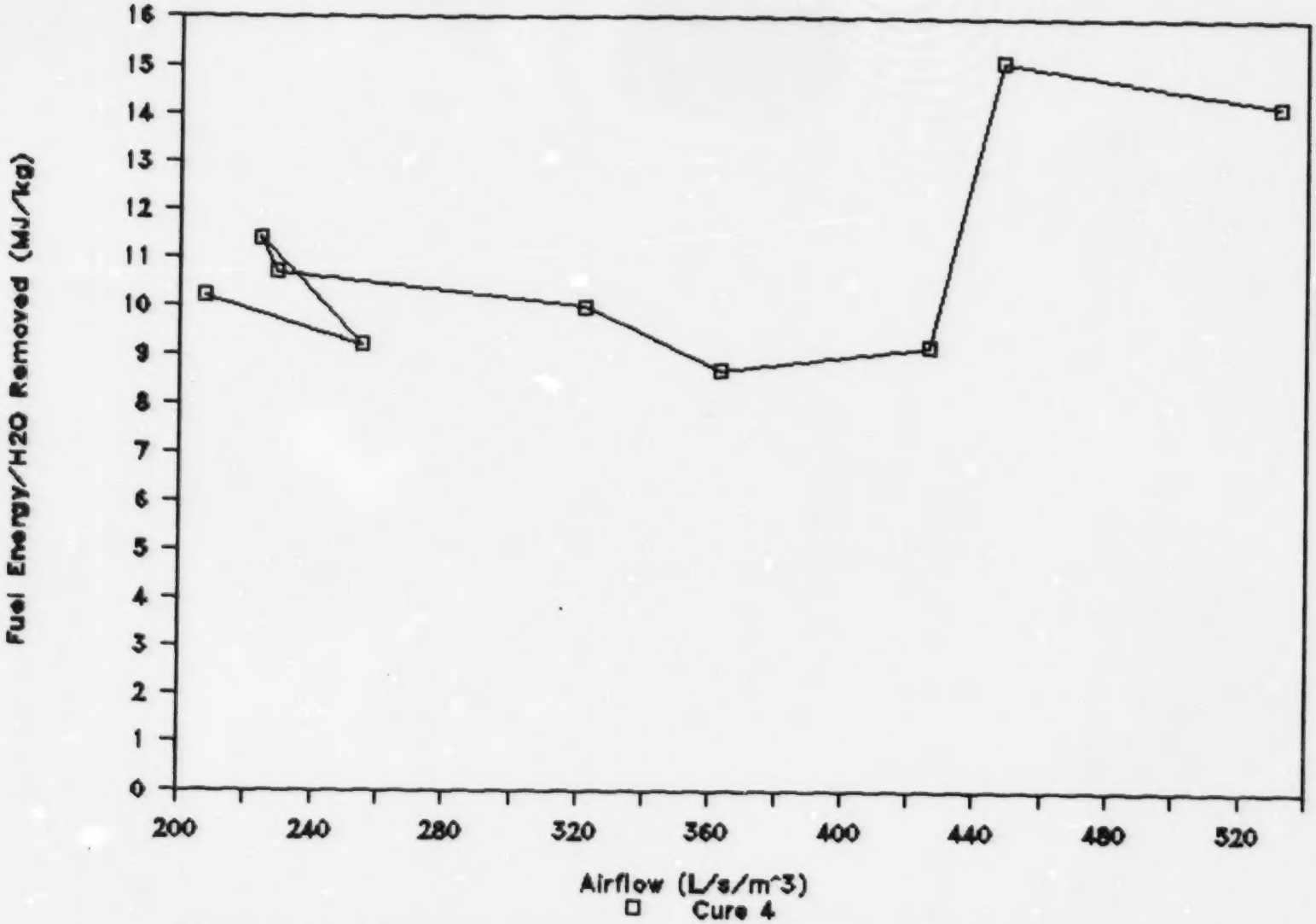

Figure 11P: Fuel energy consumed per kilogram of water removed at different airflow rates over cure 4

iii) CURING OF HAY IN BULK TOBACCO KILNS

BACKGROUND

During the spring of 1987, a group of tobacco producers belonging to the "Southern Ontario Hay Producers and Exporters Co-operative", seeded about 60 hectares of hay (alfalfa/timothy mix). One objective of the Co-operative is to export hay to race horse operations in Kentucky and Florida. The success of the new venture is highly dependent upon the quality of the hay available.

Hay buyers in the south-eastern United States demand high quality hay. Hay containing weeds is not accepted. In addition, there must be no evidence of mould or dust in the hay and most importantly the hay must have a dark green appearance.

Field drying of hay often results in a bleached product. It also results in poor leaf retention which reduces the amount of dry matter and percent protein.

Natural air drying systems (commonly referred to as mow or barn hay dryers), which are comprised of an air distribution system and fan, are used by some dairy farmers to improve hay quality. Mow hay dryers will safely dry baled hay from 25% moisture content (w.b.) to 15% moisture content (w.b.). Natural air drying of hay increases protein levels due to less leaf loss and preserves some of the natural green colour of the hay.

Members of the Co-operative felt that artificial drying of hay from somewhere between 25 to 40% moisture content (w.b.) would result in the dark green appearance the American buyers are demanding. However, natural air drying of hay from 30% moisture content (w.b.) or greater becomes very risky (House and Stone, 1987). Thus, the Co-operative decided to initiate a project which investigates heated air drying of hay from 25 to 40% moisture content (w.b.).

Heated air drying of hay should be the surest method of

insuring a consistent high quality product. It should reduce drying time, lessen the chance of mould growth and increase dry matter and protein levels as compared to field drying.

In cooperation with Carl Manary, Langton, a member of the Co-operative, the Agricultural Energy Centre assisted with and monitored a project which investigated heated air drying of baled hay in bulk tobacco kilns.

Unfortunately some difficulties establishing a good stand of hay were encountered by the Co-operative in 1987. An extremely dry spring resulted in a sparse stand of hay that became infested with weeds. The Co-operative decided it would not be in their best interests to attempt to market this hay or even spend money drying the hay from various moisture contents. Thus, only two drying tests were completed at the Manary farm in 1987. The results of these preliminary tests are reported. It is anticipated that the project will continue in 1988.

OBJECTIVES

The objective of the project was to determine if bulk tobacco kilns can be used to dry hay from moisture contents between 25% and 40% (w.b.). The success of the project will be determined by the quality of the dry hay (mostly appearance) and the drying costs.

Areas that were investigated:

a) temperature, airflow rate and length of time required to dry hay in bulk tobacco kilns;
b) energy usage and costs of drying hay in bulk tobacco kilns;
c) quality of the hay dried in bulk tobacco kilns.

METHOD

Kiln Specifications

The Manary farm is equipped with 11 "DeCloet" bulk tobacco kilns. Each kiln has a capacity of 180 racks. Inside dimensions

of the curing compartment (loading area) of each kiln is 11920 mm (length) x 3050 mm (width). The height of each kiln's curing compartment is 2440 mm (measured from perforated floor to eaves of kiln).

The blower/burner unit of each kiln is equipped with a "Delhi Industries, Model 925" centrifugal blower powered by a 5.6 kW, single phase motor. Airflow of the blower is 7200 L/s @ 470 Pa (kiln manufacturer's rating).

The burner of each kiln is direct-fired and fuelled by natural gas. The energy input of each burner is rated at 380 MJ/h.

Each kiln is insulated. A 25 mm thickness of polyurethane lines the complete interior of the kiln roof. The kiln sidewalls are insulated with 75 mm thick fiberglass.

Kiln Modifications

Two bulk kilns were modified in the same manner. The return air inlet of the blower/burner unit was blocked. Heavy plastic was stapled in front of the return air intake. This prevented moisture-laden air (with little drying potential) from being recirculated through the hay. After the drying air had passed through the hay and picked up moisture, it was allowed to exit the open loading end of the kiln (loading doors were left open).

The fresh air intake dampers on the blower/burner unit were removed to prevent restriction of the fresh air supply to the blower. In addition, the sheet metal partition above the blower/burner was raised to increase the open area for fresh air entering the blower/burner unit.

Kiln Loading

A chain type conveyor was used to load and unload the bales of hay. Each bale was placed on its edge and packed as tightly as possible over the entire floor area of the kiln. Three layers were loaded into each kiln. The orientation of the bales in the second layer was at right angles to the bales in the first and third layers.

Problems were encountered with packing the bales tightly against the open-framed centre wall of each kiln (see figure 1H). In one of the kilns this was rectified by sheathing the centre wall with sheets of plywood and panelling.

Blower/Burner Operation

The blower and burner were started immediately after completion of loading. The plenum temperature was set at 49°C. An electronic moisture probe was used to determine when the average moisture content of the hay in the top layer had reached 15% (w.b.). The burner was then turned off and the blower remained on until the hay had reached ambient temperature and when no hot spots were detectable.

MONITORING

Monitoring procedures were as follows:

1. Axle wheel scales were used to determine the hay mass before and after drying;
2. Initial and final moisture contents of the hay were determined using an oven-dry method of 65°C for 72 hours;
3. Thermocouples and a digital temperature indicator were used to record (randomly) temperatures of the ambient air, drying air and air exiting the top of the hay;
4. Natural gas and kWh meters were used to record energy usage.
5. An air velometer was used to determine airflow rates through the hay mass.

RESULTS AND EVALUATION

Curing Summary

Two cures were monitored, one in each kiln. Table 1H summarizes the data collected. Results from the cure in kiln #1 indicate that the average initial moisture content of 290 bales (7.722 tonnes) cured (in 3 layers) was 26.5% (w.b.). After

completion of curing, the average moisture content of the hay was 13.7% (w.b.). The total time required to cure the hay was 63.5 h. The blower operated continuously during this period, while the burner operated continuously for only the initial 25.5 h of the curing period.

Results from the cure in kiln #2 indicate that the average moisture content of 318 bales (9.457 tonnes) cured (in 3 layers) was 24.7% (w.b.). After completion of curing the average moisture content of the hay was 14.4% (w.b.). The length of time required to cure the hay was 42.5 h. The blower operated continuously during this period, while the burner operated continuously for only the initial 13.5 h of the curing period.

Temperature

It should be noted that during both cures the thermostat setting was 49°C. However, because of the large volume of fresh air the burner was heating, the burner did not have enough heating capacity to raise the ambient air to 49°C.

Figures 2H and 3H show the drying air and ambient air temperatures recorded (randomly) during each cure. During the cure in kiln #1, the average temperature rise of the ambient air during 25.5 h of continuous burner operation was 10.3 C°. Similarly for kiln #2, the average temperature rise of the ambient air during 13.5 h of continuous burner operation was 10.1 C°. In both cures, after the burner was shut off, the drying air temperature for the remainder of the cure was close to ambient air temperature.

Figures 4H and 5H indicate the drying air temperature (recorded randomly in the lower plenum of each kiln) as compared to the temperature of the air after passing through the three layers of hay in each kiln. Both graphs indicate that the drying air cooled as it passed through the hay. This is a result of vaporizing moisture from the hay. After the burner was shut off there was still some drying during the time the blower was operating as shown by the suppression of the exiting air temperature.

Energy Consumption

Table 2H indicates the amount of energy consumed during each cure. About 8.64 MJ (natural gas and electricity) were consumed for each kilogram of water removed during the cure in kiln #1. Results from the cure in kiln #2 indicate that about 4.97 MJ (natural gas and electricity) were consumed for every kilogram of water removed.

Based on 1987 energy prices of $0.18 per m^3 of natural gas and $0.0505 per kWh of electricity, drying costs amounted to $9.05 and $4.27 per tonne of dry hay for the cures in kiln #1 and #2, respectively.

Airflow

Calculations in Appendix 1H indicate that the airflow rates during cures in kiln #1 and #2 are estimated to be 985 and 815 L/s per tonne of dry hay, respectively.

Air velocity measurements recorded during the cure in kiln #1 indicated that only 335 L/s of air per tonne of dry hay was actually going through the hay. The remainder of the air was channelling between the centre wall of the kiln and the bales of hay. Air velocity measurements were not recorded during the cure in kiln #2. However, it was observed that there was virtually no air channelling between the wall and the bales of hay because of the plywood and panelling sheets covering the centre wall.

It should be noted that even though about the same amount of water was removed from both cures, kiln #2 cured faster and consumed less energy than kiln #1. Thus, it is very possible that eliminating the air channelling in kiln #2 resulted in significantly more efficient drying.

Hay Quality

Nutrient values of the hay were not determined because of the poor field quality. The green appearance of the hay after drying was considered fair by the Co-operative members. They indicated that probably a darker green colour could be attained from drying hay at a moisture content greater than 30% (w.b.).

CONCLUSIONS

1) Bulk kilns can be used to cure hay from about 27% moisture content (w.b.).
2) When curing hay mechanically, air channelling must be prevented, otherwise it will take longer to cure and require more energy.

RECOMMENDATIONS

Project monitoring should continue in 1988 to determine if hay above 27% moisture content can be cured successfully in bulk kilns.

LITERATURE CITED

House H. K. and Stone R. 1987. Barn hay drying. Extension bulletin. Agricultural Engineering Services, Guelph, Ontario. 6pp.

Table 1H: Summary of curing data

KILN #	BALE #	MASS (kg)		MOISTURE (%w.b.)		GAS (m^3)	HYDRO (kWh)	OPERATION OF BLOWER/BURNER (h)	
		GREEN	DRIED	GREEN	DRIED			BLOWER	BURNER
1	290	7722	6571	26.5	13.7	229.4	360	63.5	25.5
2	318	9457	8323	24.7	14.4	124.6	260	42.5	13.5

Table 2H: Energy consumption

KILN #	GAS (m^3)	HYDRO (kWh)	TOTAL ENERGY (MJ)	WATER REMOVED (kg)	ENERGY USE PER WATER REMOVED (MJ/kg)
1	229.4	360	9944	1151	8.64
2	124.6	260	5633	1134	4.97

energy content of natural gas - 37.7 MJ/m^3

energy content of electricity - 3.6 MJ/kWh

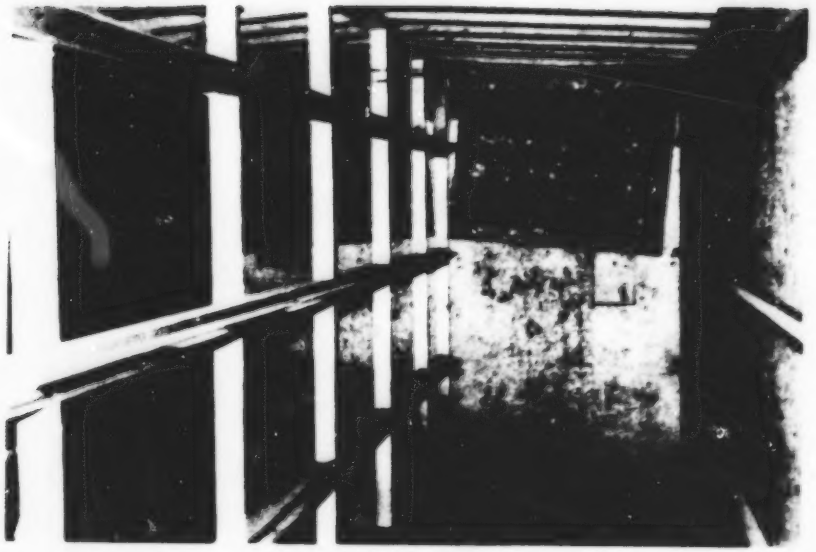

Figure 1H: Open-framed centre wall of bulk kiln

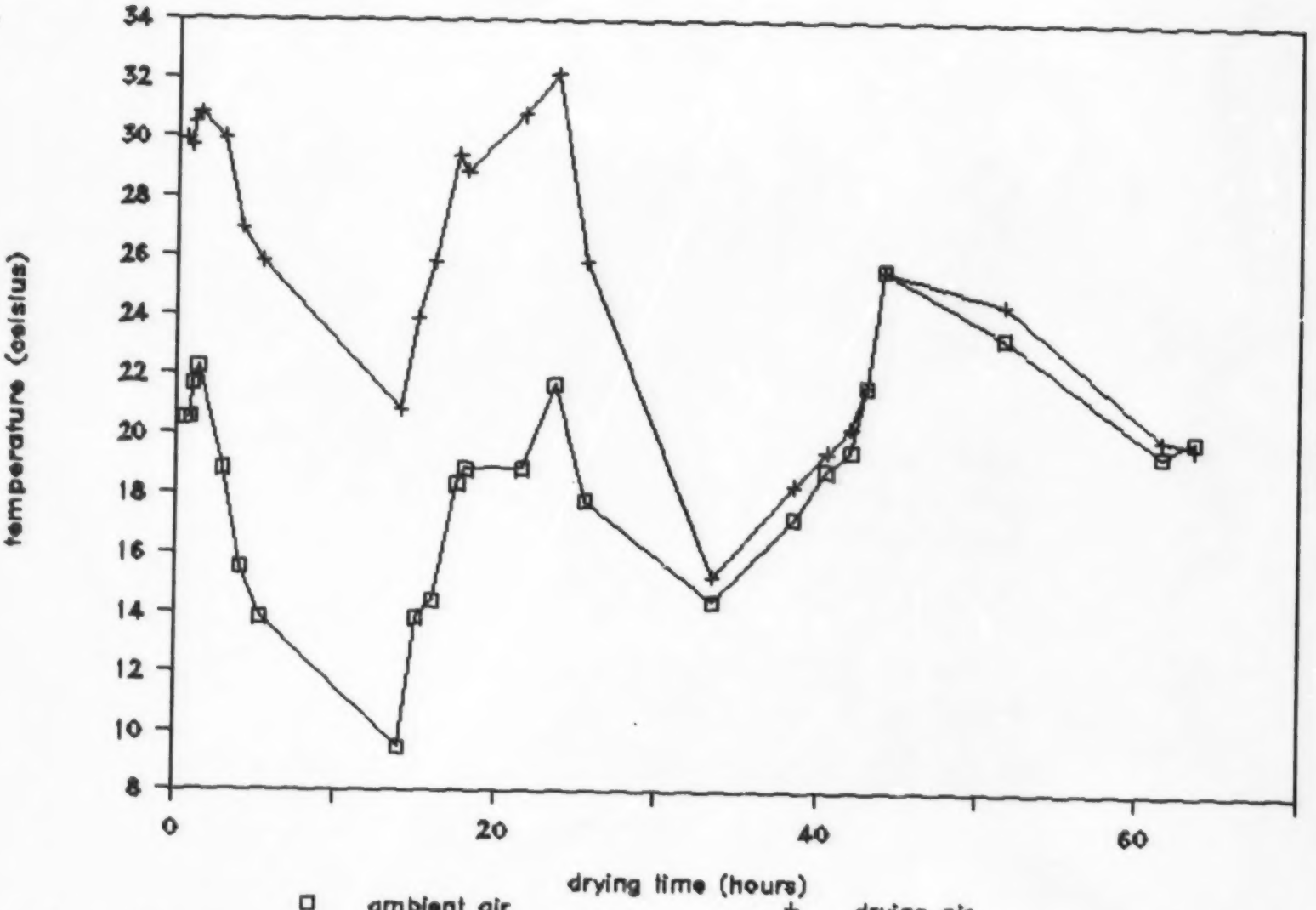

Figure 2H: Drying time vs ambient air and drying air temperatures while drying hay in kiln #1.

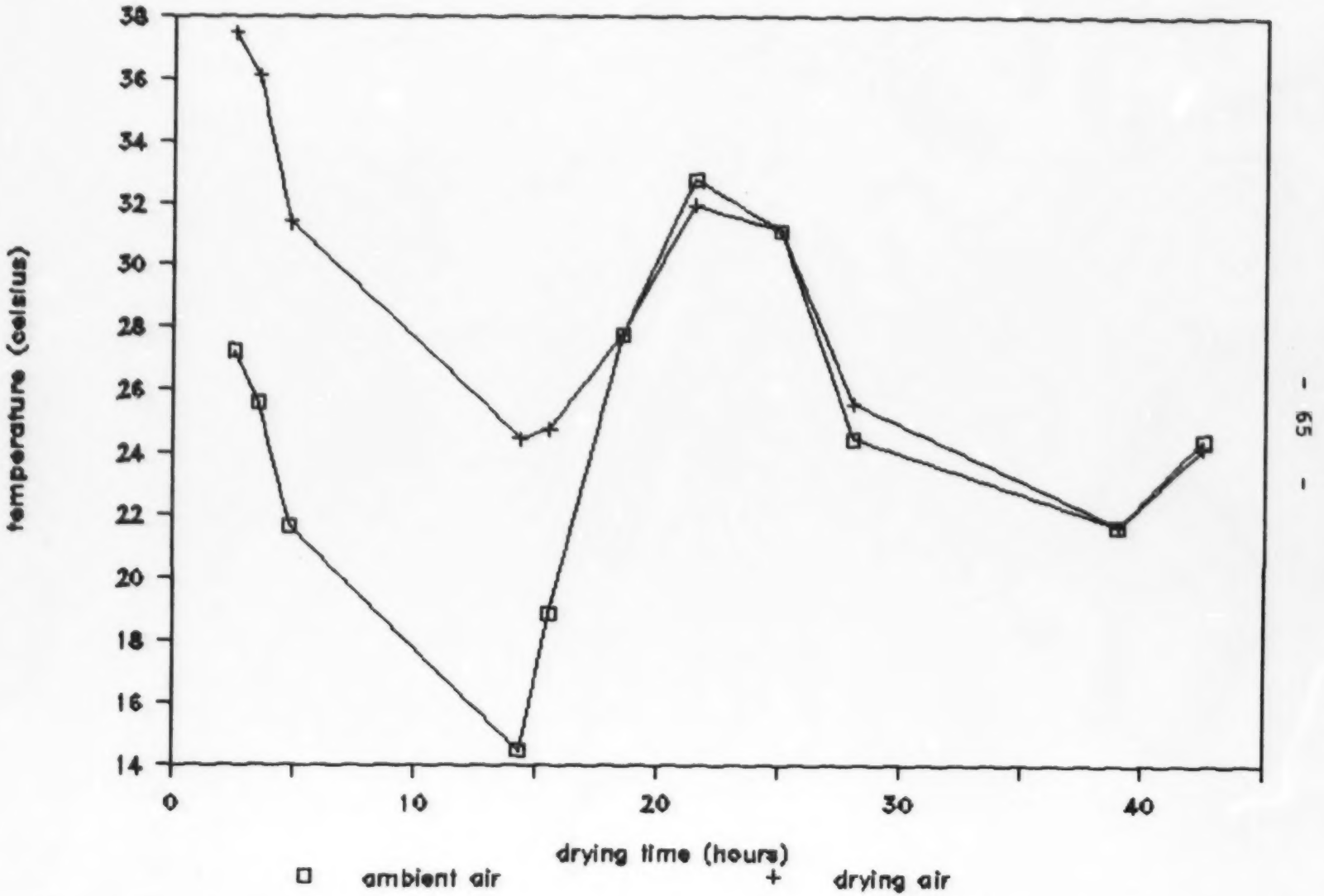

Figure 3H: Drying time vs ambient air and drying air temperatures while drying hay in kiln #2.

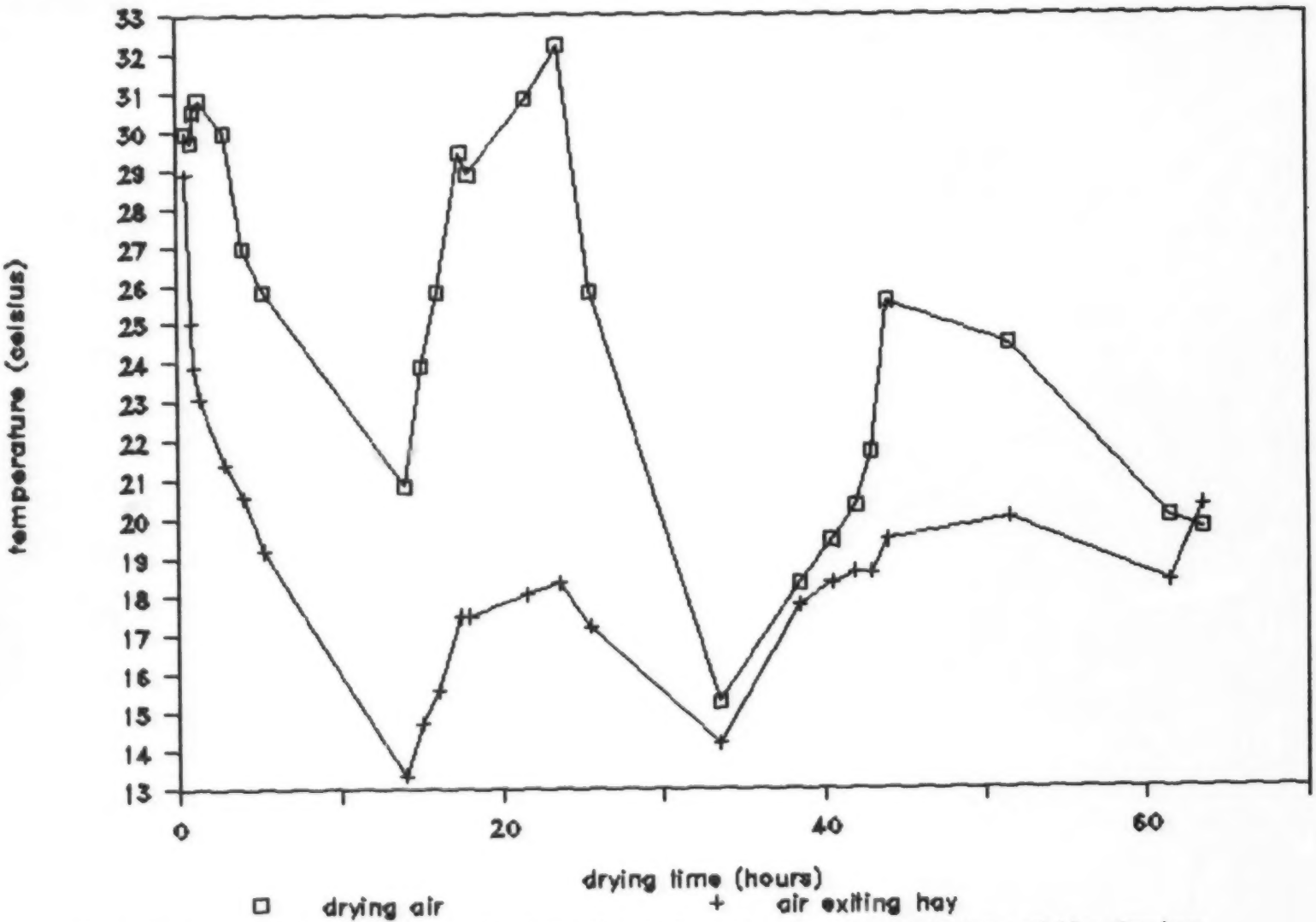

Figure 4H: Drying time vs drying air and exit air temperatures while drying hay in kiln #1.

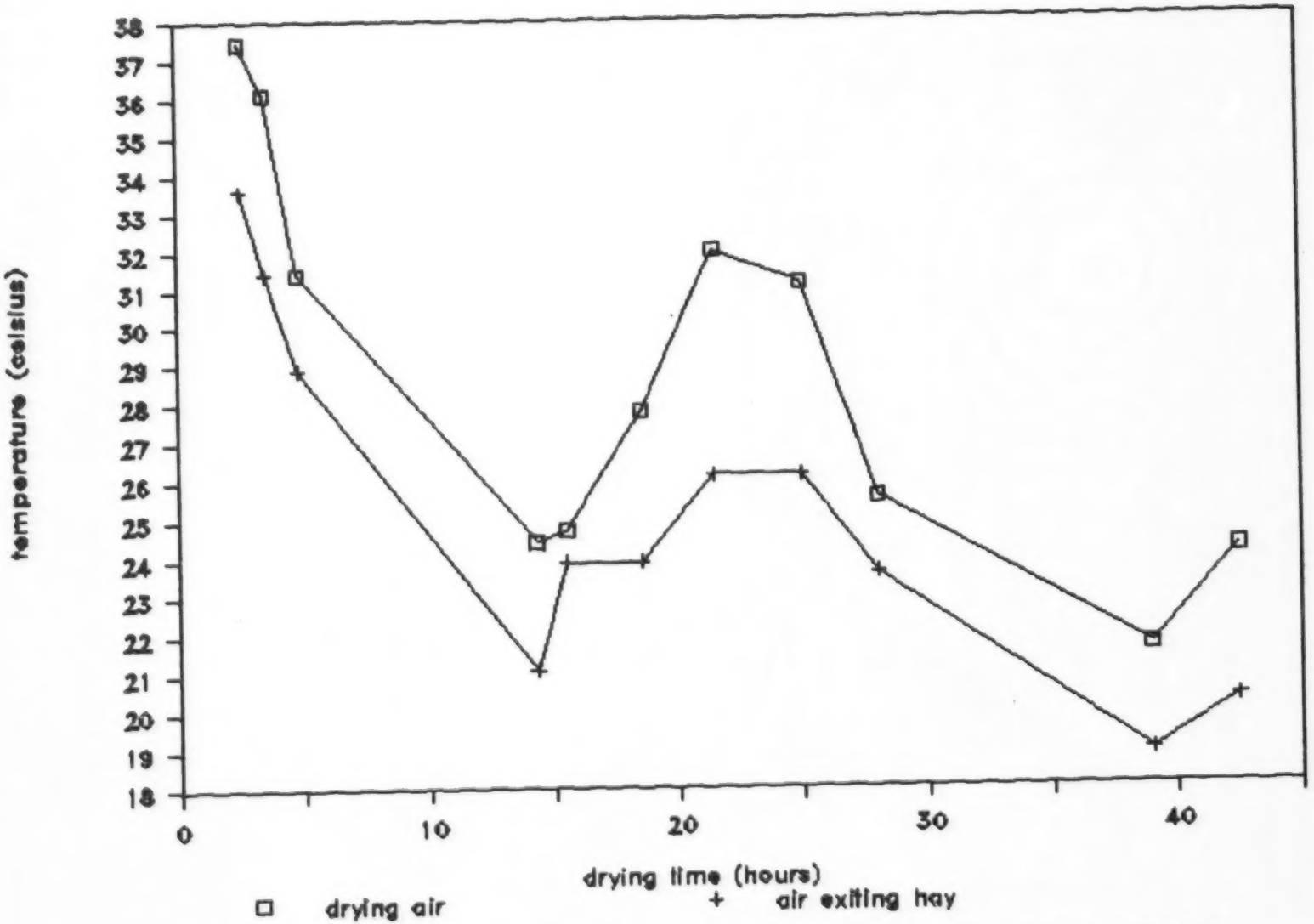

Figure 5H: Drying time vs drying air and exit air temperatures while drying hay in kiln #2.

APPENDIX 1H: Airflow Rate Calculations

Known

-Air temperature rise during burner operation in kiln #1, 10.3 C°

-Air temperature rise during burner operation in kiln #2, 10.1 C°

-Energy input of burner in kiln #1, 8648 MJ per 25.5 h or 339 MJ/h

-Energy input of burner in kiln #2, 4697 MJ per 13.5 h or 348 MJ/h

-Dried hay mass in kiln #1, 6.571 tonnes

-Dried hay mass in kiln #2, 8.323 tonnes

Assume

85% combustion efficiency of burner in kiln #1, 339 x .85 = 288 MJ/h

85% combustion efficiency of burner in kiln #2, 348 x .85 = 296 MJ/h

Determination of Airflow

Calculated mathematically by:

$$V = \frac{Q}{Cp \times Difft} \times \frac{1h}{3600\ s}$$

Where,

V = airflow L/s;

Q = heat output of burner MJ/h;

Cp = specific heat of air, 1.2 J/L•C°;

DiffT = temperature rise of air C°.

Airflow Rate Kiln #1

$$V = \frac{288\ MJ/h}{(1.2\ J/L{\cdot}C°)(10.3\ C°)} \times \frac{1h}{3600\ s}$$

V = 6472 L/s

Therefore, 6472 L/s of air per 6.571 tonnes of dry hay or 985 L/s of air per tonne of dry hay (assuming no air channelling).

Airflow Rate Kiln #2

$$V = \frac{296\ MJ/h}{(1.2\ J/L{\cdot}C°)(10.1\ C°)} \times \frac{1h}{3600\ s}$$

V = 6784 L/s

Therefore, 6784 L/s of air per 8.323 tonnes of dry hay or 815 L/s per tonne of dry hay (assuming no air channelling).